

To the King's most excellent Majesty.

Sire,

Penetrated with the deepest Sense of Your Majesty's great Goodness, in bestowing on me an annual Pension, I humbly beg that Your Majesty will be pleased to accept of my most grateful and dutiful Thanks, which is all I have to offer in return for your Royal Bounty.

That God, the Author of all Goodness may bless Your Majesty with happiness of every Kind, shall be the constant prayer of

Sire,

Your Majesty's

most dutiful,  
most obliged,  
most obedient,  
humble servant  
and subject,

James Ferguson

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A  
PLAIN METHOD  
Of determining the  
PARALLAX of VENUS,  
BY HER  
TRANSIT over the SUN:  
And from thence,  
By ANALOGY,  
The PARALLAX and DISTANCE of the SUN,  
And of all the rest of the PLANETS.

By JAMES FERGUSON.

The SECOND EDITION.

L O N D O N,

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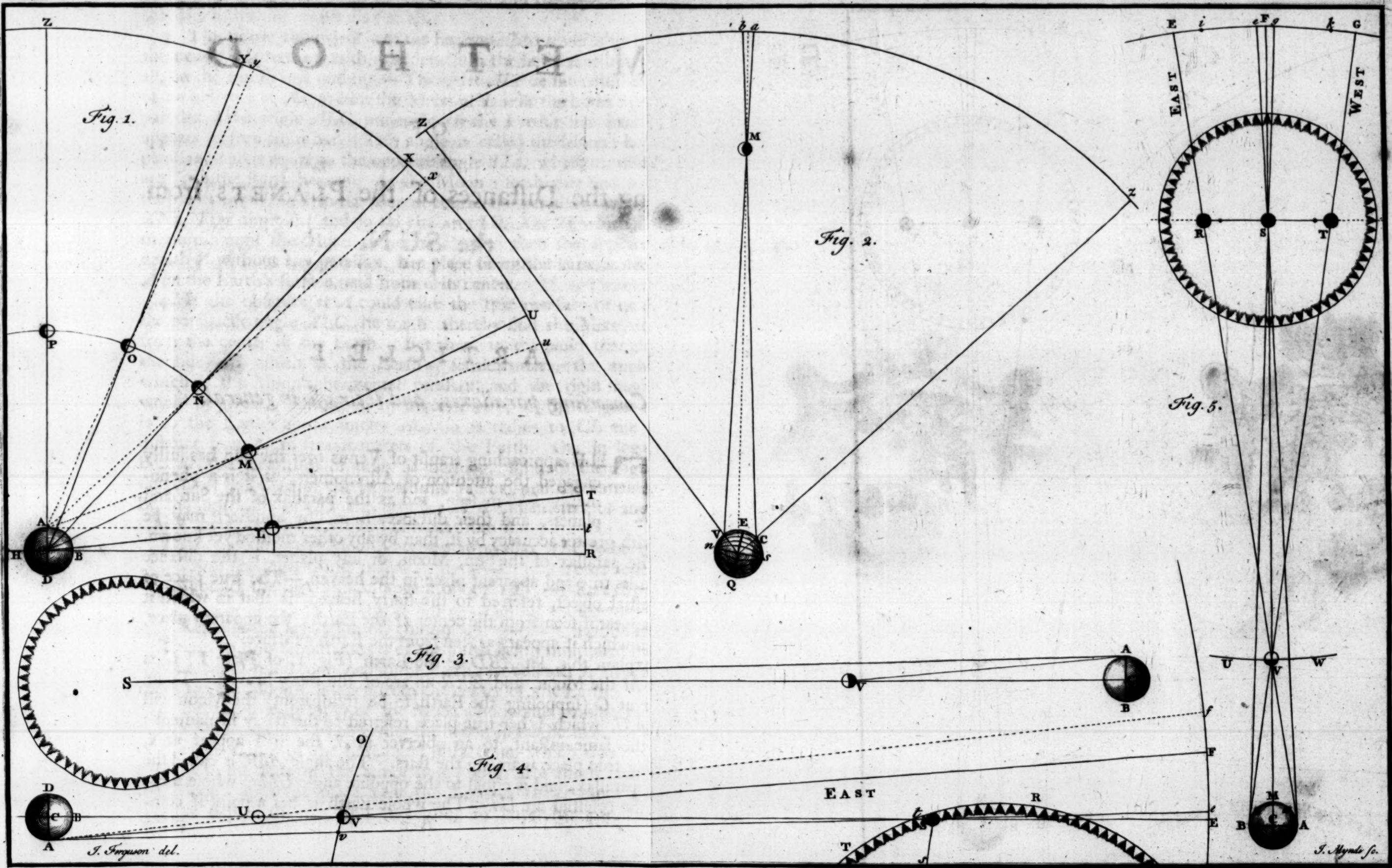
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J. Ferguson del.

J. Mynde sc.



T H E  
M E T H O D  
O F

Finding the Distances of the PLANETS from  
the SUN.

A R T I C L E I.

*Concerning parallaxes, and their use in general.*

1. **T**HE approaching transit of Venus over the Sun has justly engaged the attention of Astronomers, as it is a phenomenon seldom seen, and as the parallax of the Sun and planets, and their distances from one another, may be found with greater accuracy by it, than by any other method yet known.

2. The parallax of the Sun, Moon, or any planet, is the distance between its true and apparent place in the heaven.—The true place of any celestial object, referred to the starry heaven, is that in which it would appear if seen from the center of the Earth; the apparent place, is that in which it appears as seen from the Earth's surface.

To explain this, let  $ABD$  be the Earth (Fig. 1. of Plate I.)  $C$  its center,  $M$  the Moon, and  $ZXR$  an arc of the starry heaven. To an observer at  $C$  (supposing the Earth to be transparent) the Moon will appear at  $U$ , which is her true place referred to the starry firmament: but at the same instant, to an observer at  $A$ , she will appear at  $u$ , below her true place as among the stars. The angle  $AMC$  is called the Moon's parallax, and is equal to the opposite angle  $UMu$ , whose measure is the celestial arc  $Uu$ .—The whole Earth is but a point if com-

pared with its distance from the fixed stars, and therefore we consider the stars as having no parallax at all.

3. The nearer the object is to the horizon, the greater is its parallax; the nearer it is to the zenith, the less. In the horizon it is greatest of all, in the zenith it is nothing.—Thus, let  $ALt$  be the sensible horizon of an observer at  $A$ ; to him the Moon at  $L$  is in the horizon, and her parallax is the angle  $ALC$ , under which the Earth's semidiameter  $AC$  appears as seen from her. This angle is called the Moon's horizontal parallax, and is equal to the opposite angle  $TLt$ , whose measure is the arc  $Tt$  in the starry heaven. As the Moon rises higher and higher to the points  $M, N, O, P$  in her diurnal course, the parallactic angles  $UMu, XNx, YOy$  diminish, and so do the arcs  $Uu, Xx, Yy$  which are their measures, until the Moon comes to  $P$ ; and then she appears in the zenith  $Z$  without any parallax, her place being the same as seen from  $A$  on the Earth's surface, and from  $C$  its center.

4. If the observer at  $A$  could take the true measure or quantity of the parallactic angle  $ALC$ , he might thereby find the Moon's distance from the center of the Earth. For then, in the plain triangle  $LAC$ , the side  $AC$  which is the Earth's semidiameter, the angle  $ALC$  which is the Moon's horizontal parallax, and the right angle  $CAL$  would be given. Therefore, by trigonometry, As the tangent of  $ALC$  is to the Earth's semidiameter  $AC$ , so is radius to  $CL$  the Moon's distance from  $C$  in semidiameters of the Earth. Or, in logarithms, because the logarithm of unity is nothing, subtract the logarithmic tangent of  $ALC$  from the logarithmic radius, and the remainder will be the logarithm of  $CL$ , the number of semidiameters of the Earth, which are equal to the Moon's distance from it.

Thus, supposing the Moon's horizontal parallax  $ALC$  to be  $57' 18''$ :

|                                                |   |            |
|------------------------------------------------|---|------------|
| From the logarithmic radius                    | — | 10.0000000 |
| Subtract the logarithmic tangent of $57' 18''$ | — | 8.2218574  |
|                                                |   | —————      |

|                                 |   |           |
|---------------------------------|---|-----------|
| Remains the logarithm of 59.999 | — | 1.7781426 |
|---------------------------------|---|-----------|

Then, 59.999 semidiameters of the Earth being multiplied by 4000, the number of miles contained in the Earth's semidiameter, gives 239996 miles for the Moon's distance from the center of the Earth.

5. But the true quantity of the Moon's horizontal parallax cannot be accurately determined by observing the Moon in the horizon, on account of the inconstancy of the horizontal refractions, which always vary according to the state of the atmosphere; and, at a mean rate, elevate the Moon's apparent place near the horizon rather more than her parallax depresseth it. And therefore, to have her parallax more accurate,



accurate, Astronomers have thought of the following method, which seems to be a very good one, but hath not yet been put in practice.

Let two observers be placed under the same meridian, one in the northern hemisphere, and the other in the southern, at such a distance from each other, that the arc of the celestial meridian included between their two zeniths may be at least 80 or 90 degrees. Let each observer take the distance of the Moon's center from his zenith, by means of an exceeding good instrument, at the moment of her passing the meridian: add these two zenith-distances of the Moon together, and their excess above the distance between the two zeniths will be the distance between the two apparent places of the Moon. Then, as the sum of the natural sines of the two zenith-distances of the Moon is to radius, so is the distance between her two apparent places to her horizontal parallax: which being found, her distance from the Earth's center may be found by the analogy mentioned in § 4.

Thus, in Fig. 2. let  $VECQ$  be the Earth,  $M$  the Moon, and  $Zz$  an arc of the celestial meridian. Let  $V$  be *Vienna*, whose latitude  $EV$  is  $48^{\circ} 20'$  north; and  $C$  the *Cape of Good Hope*, whose latitude  $EC$  is  $34^{\circ} 30'$  south: both which latitudes we suppose to be accurately determined before-hand by the observers. As these two places are on the same meridian  $VECQ$ , and in different hemispheres, the sum of their latitudes  $82^{\circ} 50'$  is their distance from each other.  $Z$  is the zenith of *Vienna*, and  $z$  the zenith of the *Cape of Good Hope*; which two zeniths are also  $82^{\circ} 50'$  distant from each other, in the common celestial meridian  $Zz$ . To the observer at *Vienna*, the Moon's center will appear at  $a$  in the celestial meridian; and at the same instant, to the observer at the *Cape*, it will appear at  $b$ . Now, suppose the Moon's distance  $Za$  from the zenith of *Vienna* to be  $38^{\circ} 1' 53''$ ; and her distance  $zb$  from the zenith of the *Cape of Good Hope* to be  $46^{\circ} 4' 41''$ : the sum of these two zenith-distances ( $Za + zb$ ) is  $84^{\circ} 6' 34''$ , from which subtract  $82^{\circ} 50''$ , the distance  $Zz$  between the zeniths of these two places, and there will remain  $1^{\circ} 16' 34''$  for the arc  $ba$ , or distance between the two apparent places of the Moon's center, as seen from  $V$  and from  $C$ . Then, supposing the tabular radius to be 10000000, the natural sine of  $38^{\circ} 1' 53''$  (the arc  $Za$ ) is 6160816, and the natural sine of  $46^{\circ} 4' 41''$  (the arc  $zb$ ) is 7202821: the sum of both these sines is 13363637. Say therefore, As 13363637 is to 10000000, so is  $1^{\circ} 16' 34''$ , to  $57' 18''$ , which is the Moon's horizontal parallax.

If the two places of observation be not exactly under the same meridian, their difference of longitude must be accurately taken, that proper allowance may be made for the Moon's declination whilst she

is

is passing from the meridian of the one to the meridian of the other.

6. The Earth's diameter, as seen from the Moon, subtends an angle of double the Moon's horizontal parallax; which being supposed (as above) to be  $57' 18''$ , or  $3438''$ , the Earth's diameter must be  $1^{\circ} 54' 36''$ , or  $6876''$ . When the Moon's horizontal parallax (which is variable on account of the excentricity of her orbit) is  $57' 18''$ , her diameter subtends an angle of  $31' 2''$ , or  $1862''$ : therefore, the Earth's diameter is to the Moon's diameter, as 6876 is to 1862; that is, as 3.69 is to 1.

And since the relative bulks of spherical bodies are as the cubes of their diameters, the Earth's bulk is to the Moon's bulk, as 49.4 is to 1.

7. The parallax, and consequently the distance and bulk, of any primary planet, might be found in the above manner, if the planet was near enough to the Earth, so as to make the difference of its two apparent places sufficiently sensible: but the nearest planet is too remote for the accuracy required. In order therefore to determine the distances and relative bulks of the planets with any tolerable degree of precision, we must have recourse to a method less liable to error: and this, the approaching transit of Venus over the Sun's disc will afford us.

8. From the time of any inferior conjunction of the Sun and Venus to the next, is 583 days 22 hours 7 minutes. And, if the plane of Venus's orbit were coincident with the plane of the ecliptic, she would pass directly between the Earth and the Sun at each inferior conjunction, and would then appear like a dark round spot on the Sun for about 7 hours and 3 quarters. But Venus's orbit (like the Moon's) only intersects the ecliptic in two opposite points, called its Nodes. And therefore one half of it is on the north side of the ecliptic, and the other on the south: on which account, Venus can never be seen on the Sun, but at those inferior conjunctions which happen in or near the nodes of her orbit. At all others, she either passes above or below the Sun; and her dark side being then towards the Earth, she is therefore invisible.—The last time that this planet was seen like a spot on the Sun, was on the 24th of November old style, in the year 1639.



ARTICLE II.

*Shewing how to find the horizontal parallax of Venus by observation, and from thence, by analogy, the parallax and distance of the Sun, and of all the planets from him.*

9. In Fig. 4. of Plate I. let  $ABD$  be the Earth,  $V$  Venus, and  $TSR$  the eastern limb of the Sun. To an observer at  $B$ , the point  $t$  of that limb will be on the meridian, its place referred to the heaven will be at  $E$ , and Venus will appear just within it at  $S$ . But, at the same instant, to an observer at  $A$ , Venus is east of the Sun, in the right line  $AVF$ ; the point  $t$  of the Sun's limb appears at  $e$  in the heaven, and if Venus was then visible, she would appear at  $F$ . The angle  $CVA$  is the horizontal parallax of Venus, which we seek; and is equal to the opposite angle  $FVE$ , whose measure is the arc  $FE$ .  $ASC$  is the Sun's horizontal parallax, equal to the opposite angle  $eSE$ , whose measure is the arc  $eE$ : and  $FAe$  (the same as  $VAv$ ) is Venus's horizontal parallax from the Sun, which may be found by observing how much later in absolute time her total ingress on the Sun is, as seen from  $A$ , than as seen from  $B$ , which is the time she takes to move from  $V$  to  $v$  in her orbit  $OVv$ .

10. It appears by the tables of Venus's motion and the Sun's, that at the time of her ensuing transit, she will move  $4'$  of a degree on the Sun's disc in 60 minutes of time; and therefore she will move  $4''$  of a degree in one minute of time.

Now, let us suppose, that  $A$  is  $90^\circ$  west of  $B$ , so that when it is noon at  $B$  it will be VI in the morning at  $A$ ; that the total ingress as seen from  $B$  is at 1 minute past XII, but that as seen from  $A$  it is at 7 minutes 30 seconds past VI: deduct 6 hours for the difference of meridians of  $A$  and  $B$ , and the remainder will be 6 minutes 30 seconds for the time by which the total ingress of Venus on the Sun at  $S$  is later as seen from  $A$  than as seen from  $B$ : which time being converted into parts of a degree is  $26''$ , or the arc  $Fe$  of Venus's horizontal parallax from the Sun: for, as 1 minute of time is to 4 seconds of a degree, so is  $6\frac{1}{2}$  minutes of time to 26 seconds of a degree.

11. The

11. The times in which the planets perform their annual periods round the Sun, are already known by observation. From these times, and the universal power of gravity by which the planets are retained in their orbits, it is demonstrable, that if the Earth's mean distance from the Sun be divided into 1000 equal parts, Mercury's mean distance from the Sun must be equal to 387 of such parts; Venus's mean distance, 723; Mars's mean distance, 1524; Jupiter's, 5201; and Saturn's, 9450. Therefore, when the mean distance of any planet from the Sun in miles is known, we can by these numbers find the mean distances in miles of all the rest.

12. At the time of the ensuing transit, the Earth's distance from the Sun will be 1015, and Venus's distance from the Sun 726; which differences from the mean distances arise from the elliptical figure of the planets orbits.—Subtract 726 parts from 1015, and there will remain 289 parts for Venus's distance from the Earth at that time.

13. Divide the Sun's distance from the Earth 1015 by his distance from Venus 726, and the quotient will be 1.3967, which being multiplied into Venus's horizontal parallax from the Sun  $26''$ , will give  $36''.3142$  for her horizontal parallax as seen from the Earth at *A*; that is, for the angle *CVA*, which was to be found. Then, since the horizontal parallaxes of the celestial bodies are \* inversely as their distances from the Earth's center, As the Sun's distance 1015 is to Venus's distance 289, so is Venus's horizontal parallax  $36''.3142$  to the Sun's horizontal parallax  $10''.3397$ , on the day of the transit.—Then, to find the Sun's horizontal parallax at the time of his mean distance from the Earth's center, say, as 1000 parts, the Sun's mean distance from the Earth, is to 1015, his distance from it at the time of the transit, so is  $10''.3397$ , his horizontal parallax at that time, to  $10''.4948$ , his horizontal parallax at the time of his mean distance from the Earth.

14. This being found, we have the Sun's mean distance from the Earth's center by the following analogy. As the sine of his horizontal parallax  $10''.49$  is to unity or the Earth's semidiameter, so is radius

\* To prove this, let *S* be the Sun (Fig. 3.) *V* Venus, *AB* the Earth, *C* its center, and *AC* its semidiameter. The angle *AVC* is the horizontal parallax of Venus, and *ASC* the horizontal parallax of the Sun. But by the property of plain triangles, as the sine of *AVC* (or of *SVA* its supplement to  $180^\circ$ ) is to the sine of *ASC*, so is *AS* to *AV*, and so is *CS* to *CV*.—*N. B.* In all angles less than a minute of a degree, the sines, tangents, and arcs are so nearly equal, that they may without error be used for one another. And here we make use of *Gardiner's* logarithmic tables, because they have the sines to every second of a degree.



to the Sun's distance in semidiameters of the Earth. In logarithms thus:

|                                            |   |            |
|--------------------------------------------|---|------------|
| From the logarithmic radius                | — | 10.0000000 |
| Subtract the logarithmic sine of $10''.49$ | — | 5.7058572  |
| Remains the logarithm of 19685.3           | — | 4.2941428  |

Then, 19685.3 semidiameters of the Earth being multiplied by 4000, the number of miles contained in the Earth's semidiameter, gives 78741200 miles for the Earth's distance from the Sun.

By § 11. As 1000, the Earth's mean distance from the Sun in parts, is to 78741200, its mean distance in miles, so is 387, Mercury's mean distance from the Sun in parts, to 30462844, his mean distance from the Sun in miles.—And,

As 1000 is to 78741200, so is 723, Venus's mean distance from the Sun in parts, to 56929888, her mean distance from the Sun in miles.—Likewise,

As 1000 is to 78741200, so is 1524, Mars's mean distance from the Sun in parts, to 120001589, his mean distance from the Sun in miles.—Again,

As 1000 is to 78741200, so is 5201, Jupiter's mean distance from the Sun in parts, to 409532981, his mean distance from the Sun in miles.—Once more,

As 1000 is to 78741200, so is 9540, Saturn's mean distance from the Sun in parts, to 741191048, his mean distance from the Sun in miles.

15. The Earth's diameter, as seen from the Sun, subtends an angle of  $20''.98$  (that is, of double the Sun's horizontal parallax) at its mean distance from the Sun: and the Sun's diameter, as seen from the Earth at that time, subtends an angle of  $32' 2''$ , or  $1922''$ . Therefore, the Sun's diameter is to the Earth's diameter, as 1922 is to  $20.98$ , or as 91.1 is to 1.—And since the relative bulks of spherical bodies are as the cubes of their diameters, the Sun's bulk is to the Earth's bulk, as 756058 is to 1; supposing the Sun's mean horizontal parallax to be  $10''.49$ , as above.

16. It is plain by Fig. 4. that whether Venus be at *U* or at *V*, or in any other part of the right line *BVS*, it will make no difference in time of her total ingress on the Sun at *S*, as seen from *B*; but as seen from *A* it will. For, if Venus be at *V*, her horizontal parallax from the Sun is the arc *Fe*, which measures the angle *FAe*: but if she be nearer the Earth, as at *U*, her horizontal parallax from the Sun is the arc *fe*,  

B
which

which measures the angle  $fAe$ ; and this angle is greater than the angle  $FAe$ , by the difference of their measures  $fF$ . So that, as the distance of the celestial object from the Earth is less, its parallax is the greater.

17. To find the parallax of Venus by the above method, it is necessary, 1. That the difference of meridians of the two places of observation be  $90^\circ$ .—2. That the time of Venus's total ingress on the Sun be when his eastern limb is either on the meridian of one of the places, or very near it.—And, 3. That each observer has his clock exactly regulated to the equal time at his place. But as it might perhaps be difficult to find two places on the Earth suited to the first and second of these requisites, we shall shew how this important problem may be solved by a single observer, if he be exact as to his longitude, and has his clock truly adjusted to the equal time at his place.

18. That part of Venus's orbit in which she will move during her transit on the Sun, may be considered as a straight line; and therefore, a plane may be conceived to pass both through it and the Earth's center. To every place on the Earth's surface cut by this plane, Venus will be seen on the Sun in the same path that she would describe as seen from the Earth's center: and therefore, she will have no parallax of latitude, either north or south; but will have a greater or less parallax of longitude, as she is more or less distant from the meridian, at any time during her transit.

*Matura*, a town and fort on the south coast of the island of *Ceylon*, will be in this plane at the time of Venus's total ingress on the Sun; and the Sun will then be  $62^\circ\frac{1}{2}$  east of the meridian of that place. Consequently, to an observer at *Matura*, Venus will have a considerable parallax of longitude eastward from the Sun, when she would appear to touch the Sun's eastern limb, as seen from the Earth's center, at which the Astronomical tables suppose the observer to be placed, and give the times as seen from thence.

19. According to these tables, Venus's total ingress on the Sun will be 50 minutes after VII in the morning, at *Matura*, supposing that place to be  $80^\circ$  east longitude from the meridian of *London*; which is the observer's business to determine\*. Let us imagine that he finds it to be exactly so, but that to him the total ingress is at VII hours 55 minutes 46 seconds, which is 5 minutes 46 seconds later than the

\* The time of total ingress at *London*, as seen from the Earth's center, is at 30 minutes after II in the morning; and if *Matura* be just  $80^\circ$  (or 5 hours 20 minutes) east of *London*, when it is 30 minutes past II in the morning at *London*, it is 50 minutes past VII at *Matura*.



true calculated time of total ingress, as seen from the Earth's center. Then, as Venus's motion on (or towards, or from) the Sun is at the rate of 4 minutes of a degree in an hour, (by § 10.) her motion must be  $23''.1$  of a degree in 5 minutes 46 seconds of time: and this  $23''.1$  is her parallax, eastward from her total ingress as seen from *Matura*, when her ingress would be total if seen from the Earth's center.

20. At VII hours 50 minutes in the morning, the Sun is  $62^\circ\frac{1}{2}$  from the meridian; at VI in the morning he is  $90^\circ$  from it: therefore, as the sine of  $62^\circ\frac{1}{2}$  is to the sine of  $23''.1$ , (which is Venus's parallax from her true place on the Sun at VII hours 50 minutes,) so is radius, or the sine of  $90^\circ$ , to the sine of  $26''$ , which is Venus's horizontal parallax from the Sun at VI. In logarithms thus:

|                                           |   |            |
|-------------------------------------------|---|------------|
| As the logarithmic sine of $62^\circ 30'$ | — | 9.9479289  |
| Is to the logarithmic sine of $23''.1$    | — | 6.0481510  |
| So is the logarithmic radius              | — | 10.0000000 |

To the logarithmic sine of  $26''$  very nearly — 6.1002221

Therefore, by § 13, Venus's horizontal parallax, as seen from the Earth, must be  $36''.3142$ , and the Sun's horizontal parallax  $10''.3397$ , if the horizontal parallax of Venus from the Sun be found by observation to be  $26''$ . If it be greater, the Sun's horizontal parallax must be greater than  $10''.3397$ ; if less, the Sun's horizontal parallax must be less accordingly.

21. And thus, by a single observation, the parallax of Venus, and consequently the parallax of the Sun, might be found, if we were sure that the Astronomical tables were quite correct as to the time of Venus's total ingress on the Sun.—But although the tables may be safely depended upon for shewing the true duration of the transit, which will not be quite 6 hours from the time of Venus's total ingress on the Sun's eastern limb, to the beginning of her egress from his western; yet they may perhaps not give the true times of these two internal contacts: like a good common clock, which though it may be trusted to for measuring a few hours of time, yet perhaps it may not be quite adjusted to the meridian of the place, and consequently not true as to any one hour; which every one knows is generally the case.—Therefore, to make sure work, the observer ought to watch both the moment of Venus's total ingress on the Sun, and her beginning of egress from him, so as to note precisely the time between these two instants, by means of a good clock: and by comparing the interval at his place with the true interval as seen from the Earth's

center, which will be 5 hours 58 minutes, he may find the parallax of Venus from the Sun both at her total ingress and beginning of egress.

22. The manner of observing the transit should be as follows.—The observer being provided with a good telescope, and a pendulum clock well adjusted to the revolution of the heaven, and as near to the time at his place as conveniently may be; and having an assistant to watch the clock at the proper times, he must begin to observe the Sun's eastern limb through his telescope, twenty minutes at least before the computed time of Venus's total ingress upon it, lest there should be an error in the time thereof as given by the tables.

When he perceives a dent (as it were) to be made in the Sun's limb by the interposition of the dark body of Venus, he must then continue to watch her through the telescope as the dent increases; and his assistant must watch the time shewn by the clock, till the whole body of the planet appears just within the Sun's limb: and the moment when the bright limb of the Sun appears close by the east side of the dark limb of the planet, the observer, having a little hammer in his hand, strikes a blow therewith on the table or wall; the moment of which, the observer notes by the clock, and writes it down.

Then, let the planet pass on for about 2 hours 59 minutes, in which time it will be got to the middle of its apparent path on the Sun, and consequently will then be at its least apparent distance from the Sun's center; at which time, the observer must take its distance from the Sun's center, by means of a good micrometer, in order to ascertain its true latitude or declination from the ecliptic, and thereby find the places of its nodes.

This done, there is but little occasion to observe it any longer, until it comes so near the Sun's western limb, as almost to touch it. Then the observer watches the planet carefully with his telescope; and his assistant watches the clock, so as to note the precise moment of the planet's touching the Sun's limb, which the assistant knows by the observer's striking a blow with his hammer.

23. Although *Matura*, at the time of Venus's total ingress on the Sun, will be in a plane passing through the Earth's center, and that part of Venus's orbit wherein she moves during her transit; yet it will be considerably south of that plane at the time when her egress from the Sun begins: and therefore, as seen at that time from *Matura*, Venus will have a parallax in latitude, north of her true path, as seen from the Earth's center: and this parallax will make the time of her visible egress later, for which the observer must make proper allowance.—But *Calcutta* in *Bengal* will be in that plane when the egress begins, and  
would



would therefore be a very proper place to observe it at. So that, if the moment of total ingress was observed at *Matura*, and the beginning of egress at *Calcutta*, the horizontal parallax of Venus from the Sun might be ascertained thereby to the greatest degree of precision; because the observer at *Matura* would have the true parallax of Venus in longitude from the Sun at the beginning of the transit, and the observer at *Calcutta* would have it at the end, without being embarrassed by a parallax in latitude. But these circumstances are not indispensably necessary, since the effect of the parallax of latitude can easily be calculated, and allowed for. So that almost any place in the *East-Indies* will answer the intended purpose: and the more places there are at which observations are made, so much the better.

24. To those places where the transit begins before XII at noon, and ends after it, Venus will have an eastern parallax from the Sun at the beginning, and a western parallax from the Sun at the end; which will contract the duration of the transit, by causing it to begin later, and end sooner at these places, than it does as seen from the Earth's center; which may be explained in the following manner.

In Fig. 5. of Plate I. let *ABM* be the Earth, *V* Venus, and *S* the Sun. The Earth's motion on its axis from west to east, or in the direction *AMB*, carries an observer on that side contrary to the motion of Venus in her orbit, which is in the direction *UVW*; and will therefore cause her motion to appear quicker on the Sun's disc, than it would appear to an observer placed at the Earth's center *C*. For, if Venus was to stand still in her orbit at *V* for twelve hours, the observer on the Earth's surface would in that time be carried from *A* to *B*, through the arc *AMB*. When he was at *A*, he would see Venus on the Sun at *R*; when at *M*, he would see her at *S*; and when he was at *B*, he would see her at *T*: so that his own motion would cause the planet to appear in motion on the Sun through the line *RST*: which being in the direction of her apparent motion on the Sun as she moves in her orbit *UV*, her motion will be accelerated on the Sun to this observer, just as much as his own motion would shift her apparent place on the Sun, if she was at rest in her orbit at *V*.

But as the whole duration of the transit, from first to last internal contact, will not be quite six hours, an observer, who has the Sun on his meridian at the middle of the transit, will be carried only from *a* to *b* during the whole time thereof. And therefore, the duration will be much less contracted by his own motion, than if the planet were to be twelve hours in passing over the Sun, as seen from the Earth's center.

25. The

25. The nearer Venus is to the Earth, the greater is her parallax, and the more will the true duration of her transit be contracted thereby; the farther she is from the Earth, the contrary: so that the contraction will be in direct proportion to the parallax. Therefore, by observing, at proper places, how much the duration of the transit is less than its true duration at the Earth's center, where it is 5 hours 58 minutes, as given by the Astronomical tables, the parallax of Venus will be ascertained.

26. The above method (§ 17. & seq.) is much the same as was prescribed long ago by Doctor HALLEY, but the calculations differ considerably from his; as will appear in the next article, which contains a translation of the Doctor's whole dissertation on that subject.—He had not computed his own tables when he wrote it, nor had he time before hand to make a sufficient number of observations on the motion of Venus, so as to determine whether the nodes of her orbit are at rest or no; and was therefore obliged to trust to other tables, which are now found to be erroneous.

### A R T I C L E    I I I .

*Containing Doctor HALLEY's Dissertation on the method of finding the Sun's parallax and distance from the Earth, by the transit of Venus over the Sun's Disc, June the 6th, 1761. Translated from the Latin in Motte's Abridgement of the Philosophical Transactions, Vol. I. pag. 243; with additional notes.*

There are many things exceedingly paradoxical, and that seem quite incredible to the illiterate, which yet by means of mathematical principles may be easily solved. Scarce any problem will appear more hard and difficult, than that of determining the distance of the Sun from the Earth very near the truth: but even this, when we are made acquainted with some exact observations, taken at times fixed upon, and chosen before-hand, will without much labour be effected. And this is what I am now desirous to lay before this illustrious society\*, (which I foretell will continue for ages) that I may explain before-hand to young Astronomers, who may perhaps live to observe these things,

\* The Royal Society.



the method whereby the immense distance of the Sun may be truly obtained, to within a five hundredth part of what it really is.

It is well known that the distance of the Sun from the Earth is by different Astronomers supposed different, according to what was judged most probable from the best conjecture that each could form. *Ptolemy* and his followers, as also *Copernicus* and *Tycho Brahe*, thought it to be 1200 semidiameters of the Earth: *Kepler* 3500 nearly; *Ricciolus* doubles the distance mentioned by *Kepler*, and *Hevelius* only increases it by one half. But the planets Venus and Mercury having by the assistance of the telescope been seen in the disc of the Sun, deprived of their borrowed brightness, it is at length found, that the apparent diameters of the planets are much less than they were formerly supposed; and that the semidiameter of Venus seen from the Sun subtends no more than a fourth part of a minute, or fifteen seconds, whilst the semidiameter of Mercury, at its mean distance from the Sun, is seen under an angle only of ten seconds; that the semidiameter of Saturn seen from the Sun appears under the same angle; and that the semidiameter of Jupiter, the largest of all the planets, subtends an angle of no more than a third part of a minute at the Sun. Whence, keeping the proportion, some modern Astronomers have thought, that the semidiameter of the Earth, seen from the Sun, would subtend a mean angle between that larger one subtended by Jupiter, and that smaller one subtended by Saturn and Mercury; and equal to that subtended by Venus (namely, fifteen seconds): and have thence concluded, that the Sun is distant from the Earth almost 14000 of the Earth's semidiameters. But the same authors have on another account somewhat increased this distance: for, inasmuch as the Moon's diameter is a little more than a fourth part of the diameter of the Earth, if the Sun's parallax should be supposed fifteen seconds, it would follow, that the body of the Moon is larger than that of Mercury; that is, that a secondary planet would be greater than a primary, which would seem inconsistent with the uniformity of the mundane system. And on the contrary, the same regularity and uniformity seems scarcely to admit, that Venus, an inferior planet, that has no satellite, should be greater than our Earth, which stands higher in the system, and has such a splendid attendant. Therefore, to observe a mean, let us suppose the semidiameter of the Earth seen from the Sun, or, which is the same thing, the Sun's horizontal parallax, to be twelve seconds and a half; according to which, the Moon will be less than Mercury, and the Earth larger than Venus; and the Sun's distance from the Earth will come out nearly 16500 of the Earth's semidiameters. This distance I assent to at present, as the true.

true one, till it shall become certain what it is, by the experiment which I propose. Nor am I induced to alter my opinion by the authority of those (however weighty it may be) who are for placing the Sun at an immense distance beyond the bounds here assigned, relying on observations made upon the vibrations of a pendulum, in order to determine those exceeding small angles; but which, as it seems, are not sufficient to be depended upon: at least, by this method of investigating the parallax, it will come out sometimes nothing, or even negative; that is, the distance would either become infinite, or greater than infinite, which is absurd. And indeed, to confess the truth, it is hardly possible for a man to distinguish, with any degree of certainty, seconds, or even ten seconds, with instruments, let them be ever so skilfully made: therefore, it is not at all to be wondered at, that the excessive nicety of this matter has eluded the many and ingenious endeavours of such skilful operators.

About forty years ago, whilst I was in the island of *St. Helena*, observing the stars about the south pole, I had an opportunity of observing, with the greatest diligence, Mercury passing over the disc of the Sun; and (which succeeded better than I could have hoped for) I observed, with the greatest degree of accuracy, by means of a telescope 24 feet long, the very moment when Mercury entering upon the Sun seemed to touch its limb within, and also the moment when going off it struck the limb of the Sun's disc, forming the angle of interior contact: whence I found the interval of time, during which Mercury then appeared within the Sun's disc, even without an error of one second of time. For the lucid line intercepted between the dark limb of the planet and the bright limb of the Sun, although exceeding fine, is seen by the eye; and the little dent made in the Sun's limb, by Mercury's entering the disc, appears to vanish in a moment; and also that made by Mercury, when leaving the disc, seems to begin in an instant.—When I perceived this, it immediately came into my mind, that the Sun's parallax might be accurately determined by such kind of observations as these; provided Mercury were but nearer to the Earth, and had a greater parallax from the Sun: but the difference of these parallaxes is so little, as always to be less than the solar parallax which we want; and therefore Mercury, though frequently to be seen on the Sun, is not to be looked upon as fit for our purpose.

There remains then the transit of Venus over the Sun's disc; whose parallax, being almost four times greater than the solar parallax, will cause very sensible differences between the times in which Venus will seem to be passing over the Sun at different parts of the Earth. And  
from







from these differences, if they be observed as they ought, the Sun's parallax may be determined even to a small part of a second. Nor do we require any other instruments for this purpose, than common telescopes and clocks, only good of their kind; and in the observers, nothing more is needful than fidelity, diligence, and a moderate skill in Astronomy. For there is no need that the latitude of the place should be scrupulously observed, nor that the hours themselves should be accurately determined with respect to the meridian: it is sufficient that the clocks be regulated according to the motion of the heavens, if the times be well reckoned from the total ingress of Venus into the Sun's disc, to the beginning of her egress from it; that is, when the dark globe of Venus first begins to touch the bright limb of the Sun; which moments, I know by my own experience, may be observed to within a second of time.

But on account of the very strict laws by which the motions of the planets are regulated, Venus is seldom seen within the Sun's disc: and during the course of more than 120 years, it could not be seen once; namely, from the year 1639 (when this most pleasing sight happened to that excellent youth *Horrox* our countryman, and to him only, since the creation) to the year 1761; in which year, according to the theories which we have hitherto found agreeable to the celestial motions, Venus will again pass over the Sun on the \* 26th of May, in the morning; so that at *London*, about six o'clock in the morning, we may expect to see it near the middle of the Sun's disc, and not above four minutes of a degree south of the Sun's center. But the duration of this transit will be almost eight hours; namely, from two o'clock in the morning till almost ten. Hence the ingress will not be visible in *England*; but as the Sun will at that time be in the 16th degree of Gemini, having almost 23 degrees north declination, it will be seen without setting at all in almost all parts of the north frigid zone: and therefore the inhabitants of the coast of *Norway*, beyond the city *Nidrosia*, which is called *Drontheim*, as far as the *North Cape*, will be able to observe Venus entering the Sun's disc; and perhaps the ingress of Venus upon the Sun, when rising, will be seen by the Scotch, in the northern parts of the kingdom, and by the inhabitants of the *Schetland Isles*, formerly called *Tbule*. But at the time when Venus will be nearest the Sun's center, the Sun will be vertical to the northern shores of the bay of *Bengal*, or rather over the kingdom of *Pegu*; and therefore, in the adjacent regions, as the Sun, when Venus enters his disc, will be almost four

\* The sixth of June according to the New Style.



hours toward the east, and as many to the west when she leaves him, the apparent motion of Venus on the Sun will be accelerated by almost double the horizontal parallax of Venus from the Sun; because Venus at that time is carried with a retrograde motion from east to west, whilst an eye placed upon the Earth's surface is whirled the contrary way, from west to east\*.

Supposing

\* This has been taken already notice of in § 24; but I shall here endeavour to explain it more at large, together with some of the following part of the Doctor's Essay, by a figure.

In Fig. 1. of Plate II. let  $C$  be the center of the Earth, and  $Z$  the center of the Sun. In the right line  $CvZ$ , make  $vZ$  to  $CZ$  as 726 is to 1015 (§ 12). Let  $acbd$  be the Earth,  $v$  Venus's place in her orbit at the time of her conjunction with the Sun; and let  $TSU$  be the Sun, whose diameter is  $31' 42''$ .

The motion of Venus in her orbit is in the direction  $Nvn$ , and the Earth's motion on its axis is according to the order of the 24 hours placed around it in the figure. Therefore, supposing the mouth of the *Ganges* to be at  $G$ , when Venus is at  $E$  in her orbit, and to be carried from  $G$  to  $g$  by the Earth's motion on its axis, whilst Venus moves from  $E$  to  $e$  in her orbit; it is plain that the motions of Venus and the *Ganges* are contrary to each other.

The true motion of Venus in her orbit, and consequently the space she seems to run over on the Sun's disc in any given time, could be seen only from the Earth's center  $C$ , which is at rest with respect to its surface. And as seen from  $C$ , her path on the Sun would be in the right line  $TtU$ ; and her motion therein at the rate of four minutes of a degree per hour.  $T$  is the point of the Sun's eastern limb which Venus seems to touch at the moment of her total ingress on the Sun, as seen from  $C$ , when she is at  $E$  in her orbit; and  $U$  is the point of the Sun's western limb which she seems to touch at the moment of her beginning of egress from the Sun, as seen from  $C$ , when she is at  $e$  in her orbit.

When the mouth of the *Ganges* is at  $m$  (in revolving through the arc  $Gmg$ ) the Sun is on its meridian. Therefore, since  $G$  and  $g$  are equally distant from  $m$  at the beginning and ending of the transit, it is plain that the Sun will be as far east of the meridian of the *Ganges* (at  $G$ ) when the transit begins, as it will be west of the meridian of the same place (revolved from  $G$  to  $g$ ) when the transit ends.

But although the beginning of the transit, or rather the moment of Venus's total ingress upon the Sun at  $T$ , as seen from the Earth's center, must be when Venus is at  $E$  in her orbit, because she is then seen in the direction of the right line  $CET$ ; yet, at the same instant of time, as seen from the *Ganges* at  $G$ , she will be short of her ingress on the Sun, being then seen eastward of him, in the right line  $GEX$ , which makes the angle  $KET$  (equal to the opposite angle  $GEC$ ) with the right line  $CET$ . This angle is called the angle of Venus's parallax from the Sun, which retards the beginning of the transit as seen from the banks of the *Ganges*; so that the *Ganges*  $G$  must advance a little farther toward  $m$ , and Venus must move on in her orbit from  $E$  to  $R$ , before she can be seen from  $G$  (in the right line  $GRT$ ) wholly within the Sun's disc at  $T$ .

When Venus comes to  $e$  in her orbit, she will appear at  $U$ , as seen from the Earth's center  $C$ , just beginning to leave the Sun, that is, at the beginning of her egress from his western limb: but at the same instant of time, as seen from the *Ganges* which is then at  $g$ , she will be quite clear of the Sun toward the west; being then seen from  $g$  in the right line  $geL$ , which makes an angle, as  $UeL$  (equal to the opposite angle  $Ceg$ ) with the right line  $CeU$ : and this is the angle of Venus's parallax from the Sun as seen from the

Supposing the Sun's parallax (as we have said) to be  $12\frac{1}{2}''$ , the parallax of Venus will be  $43''$ ; from which subtracting the parallax of the Sun, there will remain  $30''$  at least for the horizontal parallax of Venus from the Sun; and therefore the motion of Venus will be increased  $45''$  at least by that parallax, whilst she passes over the Sun's disc, in those elevations of the pole which are in places near the tropic, and yet more in the neighbourhood of the equator. Now, Venus at that time will move on the Sun's disc very nearly at the rate of four minutes of a degree in an hour; and therefore 11 minutes of time at least are to be allowed for  $45''$  or three fourths of a minute of a degree; and by this space of time, the duration of this eclipse caused by Venus will, on account of the parallax, be shortened. And from this shortening of the time only, we might safely enough draw a conclusion concerning the parallax which we are in search of, provided the diameter of the Sun, and the latitude of Venus, were accurately known. But we cannot expect an exact computation in a matter of such subtilty.

We must endeavour therefore to obtain, if possible, another observation, to be taken in those places where Venus will be in the middle of the Sun's disc at midnight; that is, in places under the opposite meridian to the former, or about 6 hours or 90 degrees west of London; and where Venus enters upon the Sun a little before its setting, and goes off a little after its rising. And this will happen under the above-mentioned meridian, and where the elevation of the north pole is about 56 degrees; that is, in a part of Hudson's Bay, near a place called *Port-Nelson*. For, in this and the adjacent places, the parallax

the *Ganges* at *g*, when she is but just beginning to leave the Sun at *U*, as seen from the Earth's center *C*.

Here it is plain, that the duration of the transit about the mouth of the *Ganges* (and also in the neighbouring places) will be diminished by about double the quantity of Venus's parallax from the Sun at the beginning or ending of the transit. For Venus must be at *E* in her orbit when she is wholly upon the Sun at *T*, as seen from the Earth's center *C*: but at that time she is short of the Sun as seen from the *Ganges* at *G*, by the whole quantity of her eastern parallax from the Sun at that time, which is the angle *KET*. [This angle, in fact, is only  $23''$ ; though it is represented much larger in the figure, because the Earth therein is a vast deal too big.] Now, as Venus moves at the rate of  $4'$  in an hour, she will move  $23''$  in 5 minutes 45 seconds: and therefore, the transit will be 5 min. 45 seconds later of beginning at the banks of the *Ganges* than at the Earth's center. — When the transit is ending at *U*, as seen from the Earth's center *C*, Venus will be quite clear of the Sun (by the whole quantity of her western parallax from him) as seen from the *Ganges*, which is then at *g*: and this parallax will be  $22''$ , equal to the space through which Venus moves in 5 minutes 30 seconds of time: so that the transit will end  $5\frac{1}{2}$  minutes sooner as seen from the *Ganges*, than as seen from the Earth's center.

Hence, the whole contraction of the duration of the transit at the mouth of the *Ganges* will be 11 minutes 15 seconds of time: for it is 5 minutes 45 seconds at the beginning, and 5 minutes 30 seconds at the end.



of Venus will increase the duration of the transit by at least six minutes of time; because, whilst the Sun, from its setting to its rising, seems to pass under the pole, those places on the Earth's disc will be carried with a motion from east to west, contrary to the motion of the *Ganges*; that is, with a motion conspiring with the motion of Venus; and therefore, Venus will seem to move more slowly on the Sun, and to be longer in passing over his disc\*.

If therefore it should happen that this transit should be properly observed by skilful persons at both these places, it is clear, that the duration thereof will be 17 minutes longer, as seen from *Port-Nelson*, than as seen from the *East-Indies*. Nor is it of much consequence (if the English shall at that time give any attention to this affair) whether the observation be made at *Fort-George*, commonly called *Madras*, or at *Bencoolen* on the western shore of the island of *Sumatra*, near the equator. But if the French shall be disposed to take any pains herein, an observer may station himself conveniently enough at *Pondichery* on the west shore of the bay of *Bengal*, where the altitude of the pole is about 12 degrees. As to the Dutch, their celebrated mart at *Batavia* will afford them a place of observation fit enough for this purpose, provided they also have but a disposition to assist in advancing, in this particular,

\* In Fig. 1. of Plate II. let  $aC$  be the meridian of the eastern mouth of the *Ganges*, and  $bC$  the meridian of *Port-Nelson* at the mouth of *York-River* in *Hudson's Bay*, 56° north latitude. As the meridian of the *Ganges* revolves from  $a$  to  $c$ , the meridian of *Port-Nelson* will revolve from  $b$  to  $d$ : therefore, whilst the *Ganges* revolves from  $G$  to  $g$ , through the arc  $Gmg$ , *Port-Nelson* revolves the contrary way (as seen from the Sun or Venus) from  $P$  to  $p$ , through the arc  $Pnp$ .—Now, as the motion of Venus is from  $E$  to  $e$  in her orbit, whilst she seems to pass over the Sun's disc in the right line  $TiU$ , as seen from the Earth's center  $C$ , it is plain, that whilst the motion of the *Ganges* is contrary to the motion of Venus in her orbit; and thereby shortens the duration of the transit at that place, the motion of *Port-Nelson* is the same way as the motion of Venus, and will therefore increase the duration of the transit: which may in some degree be illustrated by supposing, that whilst a ship is under sail, if two birds fly along the side of the ship in contrary directions to each other, the bird which flies contrary to the motion of the ship will pass by it sooner than the bird will, which flies the same way that the ship moves.

In fine, it is plain by the figure, that the duration of the transit must be longer as seen from *Port-Nelson*, than as seen from the Earth's center, and longer as seen from the Earth's center, than as seen from the mouth of the *Ganges*.—For *Port-Nelson* must be at  $P$ , and Venus at  $N$  in her orbit, when she appears wholly within the Sun at  $T$ ; and the same place must be at  $p$ , and Venus at  $n$ , when she appears at  $U$ , beginning to leave the Sun.—The *Ganges* must be at  $G$ , and Venus at  $R$ , when she is seen from  $G$  upon the Sun at  $T$ ; and the same place must be at  $g$ , and Venus at  $r$ , when she begins to leave the Sun at  $U$ , as seen from  $g$ . So that Venus must move from  $N$  to  $n$  in her orbit, whilst she is seen to pass over the Sun from *Port-Nelson*; from  $E$  to  $e$  in passing over the Sun, as seen from the Earth's center; and only from  $R$  to  $r$  whilst she passes over the Sun, as seen from the banks of the *Ganges*.

the knowledge of the heavens.—And indeed I could wish that many observations of the same phenomenon might be taken by different persons at several places, both that we might arrive at a greater degree of certainty by their agreement, and also lest any single observer should be deprived, by the intervention of clouds, of a sight, which I know not whether any man living in this or the next age will ever see again; and on which depends the certain and adequate solution of a problem the most noble, and at any other time not to be attained to. I recommend it therefore, again and again, to those curious Astronomers, who (when I am dead) will have an opportunity of observing these things, that they would remember this my admonition, and diligently apply themselves with all their might to the making this observation: and I earnestly wish them all imaginable success; in the first place that they may not, by the unseasonable obscurity of a cloudy sky, be deprived of this most desirable sight; and then, that having ascertained with more exactness the magnitudes of the planetary orbits, it may redound to their immortal fame and glory.

We have now shewn, that by this method the Sun's parallax may be investigated to within its five hundredth part, which doubtless will appear wonderful to some. But if an accurate observation be made in each of the places above marked out, we have already demonstrated that the durations of this eclipse made by Venus will differ from each other by 17 minutes of time; that is, upon a supposition that the Sun's parallax is  $12\frac{1}{2}''$ . But if the difference shall be found by observation to be greater or less, the Sun's parallax will be greater or less, nearly in the same proportion. And since 17 minutes of time are answerable to  $12\frac{1}{2}$  seconds of solar parallax, for every second of parallax there will arise a difference of more than 80 seconds of time, whence, if we have this difference true to two seconds, it will be certain what the Sun's parallax is, to within a 40th part of one second; and therefore, his distance will be determined to within its 500th part at least, if the parallax be not found less than what we have supposed: for 40 times  $12\frac{1}{2}$  make 500.

And now I think I have explained this matter fully, and even more than I needed to have done, to those who understand Astronomy: and I would have them take notice, that on this occasion, I have had no regard to the latitude of Venus, both to avoid the inconvenience of a more intricate calculation, which would render the conclusion less evident; and also because the motion of the nodes of Venus is not yet discovered, nor can be determined but by such conjunctions of the planet with the Sun as this. For we conclude, that Venus will pass 4 minutes below



below the Sun's center, only in consequence of the supposition that the plane of Venus's orbit is immovable in the sphere of the fixed stars, and that its nodes remain in the same places where they were found in the year 1639. But if Venus, in the year 1761, should move over the Sun in a path more to the south, it will be manifest that her nodes have moved backward among the fixed stars; and if more to the north, that they have moved forward; and that at the rate of  $5\frac{1}{2}$  minutes of a degree in 100 Julian years, for every minute that Venus's path shall be more or less distant than the abovesaid 4 minutes from the Sun's center. And the difference between the durations of these eclipses will be somewhat less than 17 minutes of time, on account of Venus's south latitude; but greater, if by the motion of the nodes forward she should pass on the north of the Sun's center.

But for the sake of those, who though they are delighted with sidereal observations, may not yet have made themselves acquainted with the doctrine of parallaxes, I chose to explain the thing a little more fully by a scheme, and also by a calculation somewhat more accurate.

Let us suppose that at London, in the year 1761, on the 6th of June, at 55 minutes after V in the morning, the Sun will be in Gemini  $15^{\circ} 37'$ , and therefore that at its center the ecliptic is inclined toward the north, in an angle of  $6^{\circ} 10'$ : and that the visible path of Venus on the Sun's disc at that time declines to the south, making an angle with the ecliptic of  $8^{\circ} 28'$ : then the path of Venus will also be inclined to the south, with respect to the equator, intersecting the parallels of declination at an angle of  $2^{\circ} 18'$  \*. Let us also suppose, that Venus, at the forementioned time, will be at her least distance from the Sun's center, viz. only four minutes to the south; and that every hour she will describe a space of 4 minutes on the Sun, with a retrograde motion. The Sun's semidiameter will be  $15' 51''$  nearly, and that of Venus  $37\frac{1}{2}''$ . And let us suppose, for trial's sake, that the difference of the horizontal parallaxes of Venus and the Sun (which we want) is  $31''$ , such as it comes out if the Sun's parallax be supposed  $12\frac{1}{2}''$ . Then, on the center C (Plate II. Fig. 2.) let the little circle AB, representing the Earth's

\* I am convinced that this is an oversight in the Doctor, occasioned by his placing both the Earth's axis BCg (Fig. 2. of Plate II.) and the axis of Venus's orbit CH on the same side of the axis of the ecliptic CK; the former making an angle of  $6^{\circ} 10'$  therewith, and the latter an angle of  $8^{\circ} 28'$ ; the difference of which angles is only  $2^{\circ} 18'$ . But the truth is, that the Earth's axis, and the axis of Venus's orbit, will then lie on different sides of the axis of the ecliptic, the former making an angle of  $6^{\circ}$  therewith, and the latter an angle of  $8^{\circ}\frac{1}{2}$ . Therefore, the sum of these angles, which is  $14^{\circ}\frac{1}{2}$  (and not their difference  $2^{\circ} 18'$ ) is the inclination of Venus's visible path to the equator and parallels of declination.

disc,

disc, be described, and let its semidiameter  $CB$  be  $31''$ ; and let the elliptic parallels of  $22$  and  $56$  degrees of north latitude (for the *Ganges* and *Port-Nelson*) be drawn within it, in the manner now used by Astronomers for constructing solar eclipses. Let  $BCg$  be the meridian in which the Sun is, and to this, let the right line  $FHG$ , representing the path of Venus, be inclined at an angle of  $2^{\circ} 18'$ ; and let it be distant from the center  $C$   $240$  such parts, whereof  $CB$  is  $31$ . From  $C$  let fall the right line  $CH$ , perpendicular to  $FG$ ; and suppose Venus to be at  $H$  at  $55$  minutes after  $V$  in the morning. Let the right line  $FHG$  be divided into the horary spaces  $III$   $IV$ ,  $IV$   $V$ ,  $V$   $VI$ , &c. each equal to  $CH$ ; that is, to  $4$  minutes of a degree. Also, let the right line  $LM$  be equal to the difference of the apparent semidiameters of the Sun and Venus, which is  $15' 13\frac{1}{2}''$ ; and a circle being described with the radius  $LM$ , on a center taken in any point within the little circle  $AB$  representing the Earth's disc, will meet the right line  $FG$  in a point denoting the time at *London* when Venus shall touch the Sun's limb internally, as seen from the place of the Earth's surface that answers to the point assumed in the Earth's disc. And if a circle be described on the center  $C$ , with the radius  $LM$ , it will meet the right line  $FG$  in the points  $F$  and  $G$ ; and the spaces  $FH$  and  $GH$  will be each equal to  $14' 4''$ , which space Venus will appear to pass over in  $3$  hours  $40$  minutes of time at *London*; therefore,  $F$  will fall in  $II$  hours  $15$  minutes, and  $G$  in  $IX$  hours  $35$  minutes in the morning. Whence it is manifest, that if the magnitude of the Earth, on account of its immense distance, should vanish as it were into a point; or, if being deprived of a diurnal motion, it should always have the Sun vertical to the same point  $C$ , the whole duration of this eclipse would be  $7$  hours  $20$  minutes. But the Earth in that time being whirled through  $110$  degrees of longitude, with a motion contrary to the motion of Venus, and consequently the abovementioned duration being contracted, suppose  $12$  minutes, it will come out  $7$  hours  $8$  minutes, or  $107$  degrees, nearly.

Now, Venus will be at  $H$ , at her least distance from the Sun's center, when in the meridian of the eastern mouth of the *Ganges*, where the altitude of the pole is about  $22$  degrees. The Sun therefore will be equally distant from the meridian of that place, at the moments of the ingress and egress of the planet, viz.  $53\frac{1}{2}$  degrees; as the points  $a$  and  $b$  (representing that place in the Earth's disc  $AB$ ) are, in the greater parallel, from the meridian  $BCg$ . But the diameter  $ef$  of that parallel will be to the distance  $ab$ , as the square of the radius to the rectangle under the sines of  $53\frac{1}{2}$  and  $68$  degrees; that is, as  $1' 2''$  to  $46'' 13'''$ . And by a good calculation, (which, that I may not tire the reader, it is better



to omit) I find, that a circle described on  $a$  as a center, with the radius  $LM$ , will meet the right line  $FH$  in the point  $M$ , at II hours 20 minutes 40 seconds; but that being described round  $b$  as a center, it will meet  $HG$  in the point  $N$  at IX hours 29 minutes 22 seconds, according to the time reckoned at *London*: and therefore, Venus will be seen entirely within the Sun at the banks of the *Ganges* for 7 hours 8 minutes 42 seconds: we have then rightly supposed that the duration will be 7 hours 8 minutes, since the part of a minute is here of no consequence.

But adapting the calculation to *Port-Nelson*, I find, that the Sun being about to set, Venus will enter his disc; and immediately after his rising she will leave the same. That place is carried in the intermediate time through the hemisphere opposite to the Sun, from  $c$  to  $d$ , with a motion conspiring with the motion of Venus; and therefore, the stay of Venus on the Sun will be about 4 minutes longer, on account of the parallax; so that it will be at least 7 hours 24 minutes, or 111 degrees of the equator. And since the latitude of the place is 56 degrees, as the square of the radius is to the rectangle contained under the sines of  $55\frac{1}{2}$  and 34 degrees, so is  $AB$  which is  $1' 2''$ , to  $cd$  which is  $28'' 33'''$ . And if the calculation be justly made, it will appear, that a circle described on  $c$  as a center: with the radius  $LM$ , will meet the right line  $FH$  in  $O$ , at II hours 12 minutes 45 seconds; and that such a circle described on  $d$  as a center will meet  $HG$  in  $P$ , at IX hours 36 minutes 37 seconds; and therefore the duration at *Port-Nelson* will be 7 hours 23 minutes 52 seconds, which is greater than at the mouth of the *Ganges*, by 15 minutes 10 seconds of time. But if Venus should pass over the Sun without having any latitude, the difference would be 18 minutes 40 seconds; and if she should pass  $4'$  north of the Sun's center, the difference would amount to 21 minutes 40 seconds, and will be still greater, if the planet's north latitude be more increased.

From the foregoing hypothesis it follows, that at *London*, when the Sun rises, Venus will have entered his disc; and that, at IX hours 37 minutes in the morning, she will touch the limb of the Sun internally in going off; and lastly, that she will not entirely leave the Sun till IX hours 56 minutes.

It likewise follows from the same hypothesis, that the center of Venus should just touch the Sun's northern limb in the year 1769, on the third of June, at XI o'clock at night. So that, on account of the parallax, it will appear in the northern parts of *Norway* entirely within the Sun, which then does not set to those parts; whilst, on the coasts of

of *Peru* and *Chili* it will seem to travel over a small portion of the disc of the setting Sun; and over that of the rising Sun at the *Molucca Islands*, and in their neighbourhood.—But if the nodes of Venus be found to have a retrograde motion (as there is reason to believe from some later observations they have) then Venus will be seen every where within the Sun's disc; and will afford a much better method for finding the Sun's parallax, by almost the greatest difference in the durations of these eclipses that can possibly happen.

But how this parallax may be deduced from observations made somewhere in the *East-Indies*, in the year 1761, both of the ingress and egress of Venus, and compared with those made in its going off with us; namely, by applying the angles of a triangle given in specie to the circumference of three equal circles; shall be explained on some other occasion.

#### ARTICLE IV.

*Shewing that the whole method proposed by the Doctor cannot be put in practice, and why.*

27. In the above Dissertation, the Doctor has explained his method with great modesty, and even with some doubtfulness with regard to its full success. For he tells us, that the Sun's parallax may only be determined within its five hundredth part thereby, provided it be not less than  $12\frac{1}{2}''$ , that there may be a good observation made at *Port-Nelson*, as well as about the banks of the *Ganges*, and that Venus does not pass more than 4 minutes of a degree below the center of the Sun's disc.—He has taken all proper pains not to raise our expectations too high, and yet, from his well known abilities, and character as a great Astronomer, it seems mankind in general have laid greater stress upon his method than he ever desired them to do. Only, as he was convinced it was the best method by which this important problem can ever be solved, he recommended it warmly for that reason. He had not then made a sufficient number of observations whereby to determine, with certainty, whether the nodes of Venus's orbit have any motion at all; or, if they have, whether it be backward or forward with respect to the stars. And consequently, having not then made his own tables, he was obliged to calculate from the best that he could find. But those tables allow of no motion to Venus's nodes, and also reckon her conjunction with the Sun to be about half an hour too late.

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28. But

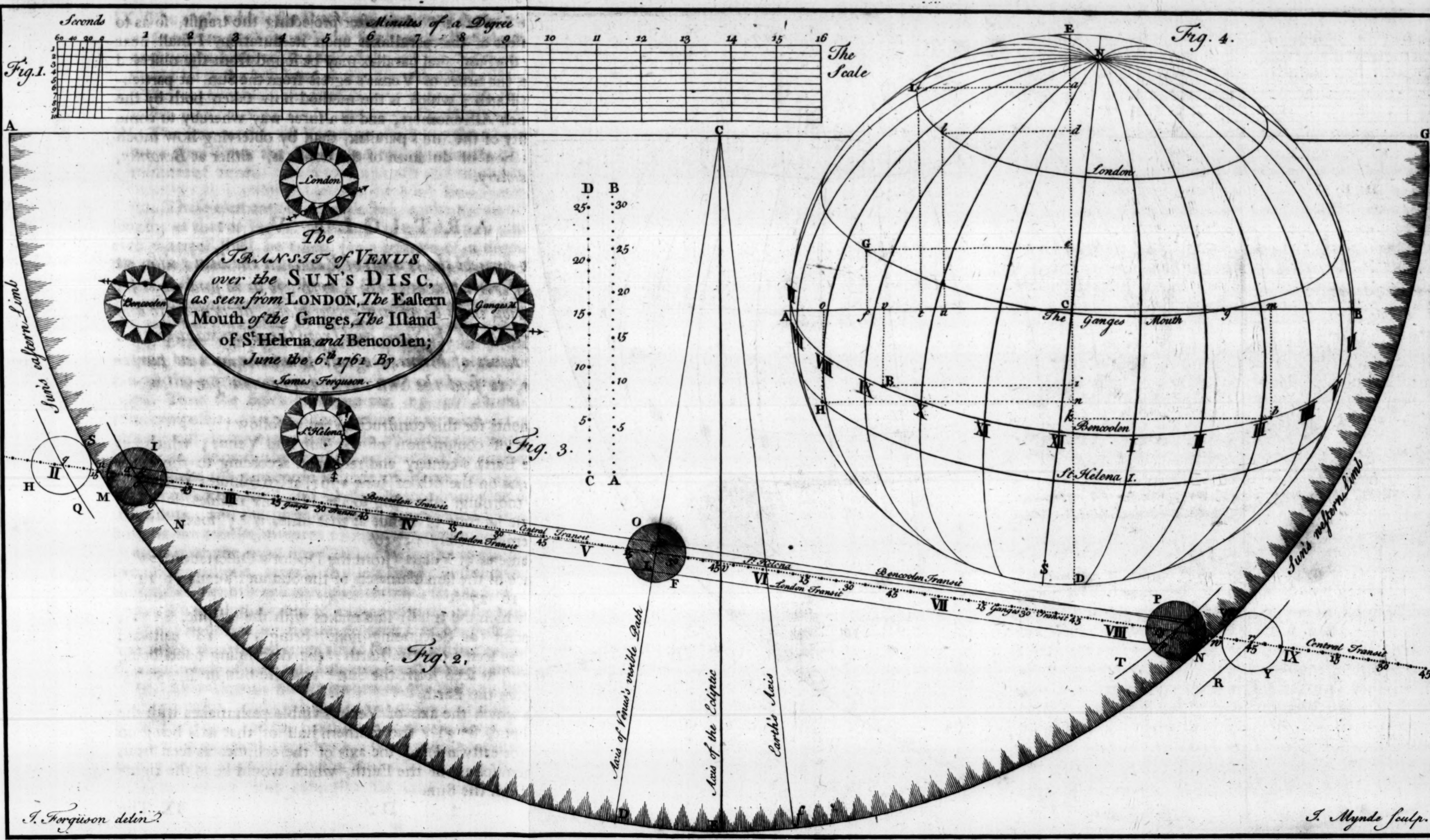


28. But more modern observations prove that the nodes of Venus's orbit have a motion, backward, or contrary to the order of the signs, with respect to the fixed stars. And this motion is allowed for, in the Doctor's tables, a great part whereof were made from his own observations. And it appears by these tables, that Venus will be so much farther past her descending node at the time of this transit, than she was past her ascending node at her transit in November 1639, that instead of passing only 4 minutes of a degree below the Sun's center in this, she will pass almost 10 minutes of a degree below it: on which account, the line of her transit will be so much shortened, as will make her stay on the Sun's disc about an hour and 20 minutes less than if she passed only 4 minutes below the Sun's center, at the middle of her transit. And therefore, her parallax from the Sun will be so much diminished both at the beginning and end of her transit, at all places from which the whole of it will be seen, that the difference of its durations, as seen from them, and as supposed to be seen from the Earth's center, will not amount to 11 minutes of time.

29. But this is not all: for although the transit will begin before the Sun sets to *Port-Nelson*, it will be quite over before he rises to that place next morning, on account of its ending so much sooner than as given by the tables to which the Doctor was obliged to trust. So that we are quite deprived of the advantage that otherwise would have arisen from observations made at *Port-Nelson*.

30. In order to trace this affair through all its intricacies, and to render it as intelligible to the reader as I can, there will be an unavoidable necessity of dwelling much longer upon it than I could otherwise wish. And as it is impossible to lay down truly the parallels of latitude, and the situations of places at particular times, in such a small disc of the Earth as must be projected in such a sort of diagram as the Doctor has given, so as to measure thereby the exact times of the beginning and ending of the transit at any given place, unless the Sun's disc be made at least 30 inches diameter in the projection; and to which the Doctor did not quite trust without making some calculations; I shall take a different method, in which the Earth's disc may be made as large as the operator pleases: but if he makes it only 6 inches in diameter, he may measure the quantity of Venus's parallax from the Sun upon it, both in longitude and latitude, to the fourth part of a second, for any given time and place; and then, by an easy calculation in the common rule of three, he may find the effect of the parallax on the duration of the transit. In this, I shall first suppose with the Doctor, that the Sun's horizontal parallax is  $12\frac{1}{2}''$ ; and consequently, that Venus's horizontal  
parallax:







parallax from the Sun is  $31''$ . And after projecting the transit, so as to find the total effect of the parallaxes upon its duration, I shall next shew how nearly the Sun's real parallax may be found from the observed intervals between the times of Venus's egress from the Sun, at particular places of the Earth; which is the method now taken both by the English and French Astronomers, and is a surer way whereby to come at the real quantity of the Sun's parallax, than by observing how much the whole contraction of duration of the transit is, either at Bencoolen, Batavia, or Pondichery.

## ARTICLE V.

*Shewing how to project the transit of Venus on the Sun's disc, as seen from different places of the Earth; so as to find what its visible duration must be at any given place, according to any assumed parallax of the Sun; and from the observed intervals between the times of Venus's egress from the Sun at particular places, to find the Sun's true horizontal parallax.*

31. The elements for this construction are as follow:

- I. The true time of conjunction of the Sun and Venus; which, as seen from the Earth's center, and reckoned according to the equal time at London, is on the 6th of June 1761, at 46 minutes 17 seconds after V in the morning, according to Dr. HALLEY's tables.
- II. The geocentric latitude of Venus at that time,  $9^{\circ} 43''$  south.
- III. The Sun's semidiameter,  $15' 50''$ .
- IV. The semidiameter of Venus (from the Doctor's Dissertation)  $37\frac{1}{2}''$ .
- V. The Difference of the semidiameters of the Sun and Venus  $15' 12\frac{1}{2}''$ .
- VI. Their sum,  $16' 27\frac{1}{2}''$ .
- VII. The angle which the transit-line makes with the ecliptic,  $8^{\circ} 31'$ ; the angular point (or descending node) being  $1^{\circ} 6' 18''$  eastward from the Sun, as seen from the Earth; the descending node being in  $\Gamma 14^{\circ} 29' 37''$ , as seen from the Sun; and the Sun in  $\Pi 15^{\circ} 35' 55''$ , as seen from the Earth.
- VIII. The angle which the axis of Venus's visible path makes with the axis of the ecliptic,  $8^{\circ} 31'$ ; the southern half of that axis being on the left hand (or eastward) of the axis of the ecliptic, as seen from the northern hemisphere of the Earth, which would be to the right-hand, as seen from the Sun.

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IX. The

- IX. The angle which the Earth's axis makes with the axis of the ecliptic, as seen from the Sun,  $6^\circ$ ; the southern half of the Earth's axis lying to the right-hand of the axis of the ecliptic, in the projection; which would be to the left-hand as seen from the Sun.
- X. The angle which the Earth's axis makes with the axis of Venus's visible path,  $14^\circ 31'$ : viz. the sum of N<sup>o</sup> VIII and IX.
- XI. The true motion of Venus on the Sun, given by the tables as if it were seen from the Earth's center, 4 minutes of a degree in 60 minutes of time.

32. These elements being collected, make a scale of any convenient length, as that of Fig. 1. in Plate III, and divide it into 17 equal parts, each whereof shall be taken for a minute of a degree: then, divide the minute next to the left-hand into 60 equal parts for seconds, by diagonal lines, as in the figure. The reason for dividing the scale into 17 parts or minutes is, because the sum of the semidiameters of the Sun and Venus exceeds 16 minutes of a degree. See N<sup>o</sup> VI.

33. Draw the right line *ACG* (Fig. 2.) for a small part of the ecliptic, and perpendicular thereto draw the right line *CvE* for the axis of the ecliptic on the southern half of the Sun's disc.

34. Take the Sun's semidiameter,  $15' 50''$ , from the scale with your compasses; and with that extent, as a radius, set one foot in *C* as a center, and describe the semicircle *AEG* for the southern half of the Sun's disc; because the transit is on that half of the Sun.

35. Take the geocentric latitude of Venus,  $9' 43''$ , from the scale with your compasses; and set that extent from *C* to *v*, on the axis of the ecliptic: and the point *v* shall be the place of Venus's center on the Sun, at the tabular moment of her conjunction.

36. Draw the right line *CBD*, making an angle of  $8^\circ 31'$  with the axis of the ecliptic, toward the left hand; and this line shall represent the axis of Venus's geocentric visible path on the Sun.

37. Through the point of conjunction *v*, in the axis of the ecliptic, draw the right line *qtr* for the geocentric visible path of Venus over the Sun's disc, at right angles to *CBD* the axis of her orbit, which axis will divide the line of her path into two equal parts *qt* and *tr*.

38. Take Venus's horary motion on the Sun,  $4'$ , from the scale with your compasses; and with that extent make marks along the transit-line *qtr*. The equal spaces, from mark to mark, shew how much of that line Venus moves through in each hour, as seen from the Earth's center, during her continuance on the Sun's disc.

39. Divide



39. Divide each of these horary spaces, from mark to mark, into 60 equal parts for minutes of time; and set the hours to the proper marks in such a manner, that the true time of conjunction of the Sun and Venus,  $46\frac{1}{2}$  minutes after V in the morning, may fall into the point *v*, where the transit-line cuts the axis of the ecliptic. So the point *v* shall denote the place of Venus's center on the Sun, at the instant of conjunction; and *t* (in the axis *CD* of her orbit) will be the middle of her transit; which is at 24 minutes after V in the morning, as seen from the Earth's center, and reckoned by the equal time at *London*.

40. Take the difference of the semidiameters of the Sun and Venus,  $15' 12\frac{1}{2}''$ , in your compasses from the scale; and with that extent, setting one foot in the Sun's center *C*, describe the arcs *N* and *T* with the other, crossing the transit-line in the points *k* and *l*; which are the points on the Sun's disc that are hid by the center of Venus at the moments of her two internal contacts with the Sun's limb or edge, at *M* and *N*: the former of these is the moment of Venus's total ingress on the Sun, as seen from the Earth's center, which is at 28 minutes after II in the morning, as reckoned at *London*; and the latter is the moment when her egress from the Sun begins, as seen from the Earth's center, which is 20 minutes after VIII in the morning at *London*. The interval between these two contacts is 5 hours 52 minutes.

41. The central ingress of Venus on the Sun is the moment when her center is on the Sun's eastern limb at *u*, which is at 15 minutes after II in the morning; and her central egress from the Sun is the moment when her center is on the Sun's western limb at *w*; which is at 33 minutes after VIII in the morning, as seen from the Earth's center, and reckoned according to the time at *London*. The interval between these is 6 hours 18 minutes.

42. Take the sum of the semidiameters of the Sun and Venus,  $16' 27\frac{1}{2}''$ , in your compasses from the scale; and with that extent, setting one foot in the Sun's center *C*, describe the arcs *Q* and *R* with the other, cutting the transit-line in the points *q* and *r*, which are the points in open space (clear of the Sun) where the center of Venus is, at the moments of her two external contacts with the Sun's limb at *S* and *W*; or the moments of the beginning and ending of the transit, as seen from the Earth's center; the former of which is at 3 minutes after II in the morning at *London*, and the latter at 45 minutes after VIII. The interval between these is 6 hours 42 minutes.

43. Take the semidiameter of Venus,  $37\frac{1}{2}''$ , in your compasses from the scale; and with that extent as a radius, on the points *q*, *k*, *t*, *l*, *r*, as centers, describe the circles *HS*, *MI*, *OF*, *PN*, *WT*, for the disc of Venus,

Venus, at her first contact at *S*, her total ingress at *M*, her place *OF* on the Sun at the middle of her transit, her beginning of egress at *N*, and her last contact at *W*.

44. Those who have a mind to project the Earth's disc on the Sun, round the center *C*, and to lay down the parallels of latitude and situations of places thereon, according to Dr. HALLEY's method, may draw *Cf* for the axis of the Earth, produced to the southern edge of the Sun at *f*; and making an angle *ECf* of  $6^\circ$  with the axis of the ecliptic *CE*: but he will find it very difficult and uncertain to mark the places on that disc, unless he makes the Sun's semidiameter *AC* 15 inches at least: otherwise *Cf* is of no use at all in this projection.

45. In Fig. 3. of Plate III. make the line *AB* of any convenient length, and divide it into 31 equal parts, each whereof shall be taken for a second of Venus's parallax either from or upon the Sun (her horizontal parallax from the Sun being  $31''$ ); and taking the whole length *AB* in your compasses, set one foot in *C* (Fig. 4.) as a center, and describe the circle *AEBD* for the Earth's enlightened disc, whose diameter is  $62''$ , or double the horizontal parallax of Venus from the Sun. In this disc, draw *ACB* for a small part of the ecliptic, and at right angles thereto draw *ECD* for the axis of the ecliptic. Draw also *NCS* both for the Earth's axis and universal solar meridian, making an angle of  $6^\circ$  with the axis of the ecliptic, as seen from the Sun.

46. This figure represents the Earth's enlightened disc, as seen from the Sun at the time of the transit. The parallels of latitude of *London*, the eastern mouth of the *Ganges*, *Bencoolen*, and the island of *St. Helena*, are laid down in it, in the same manner as they would appear to an observer on the Sun, if they were really drawn in circles on the Earth's surface (like those on a common terrestrial globe) and could be visible at such a distance.—But, as the rules for delineating them in such a figure are too long to be inserted here (and would also occasion a confusion in the figure by a great many more lines than what are in it already) since these rules are exactly the same as those prescribed for such delineations in the geometrical construction of solar eclipses, I beg leave to refer those readers, who are not already acquainted with such projections, to my book of Astronomy, sold by Mr. Millar in the Strand, London; wherein the whole method is described.

47. The points where the curve-lines (called hour-circles) XI *N*, XII *N*, &c. cut the parallels of latitude, or paths of the four places above mentioned, are the points at which the places themselves would appear in the disc, as seen from the Sun, at these hours respectively. When either place comes to the solar meridian *NCS* by the Earth's rotation



rotation on its axis, it is noon at that place; and the difference, in absolute time, between the noon at that place and the noon at any other place, is in proportion to the difference of longitude of these two places, reckoning one hour for every 15 degrees of longitude, and 4 minutes for each degree: adding the time if the longitude be east, but subtracting it if the longitude be west.

48. The distance of either of these places from the axis of the ecliptic *ECD*, at any hour or part of an hour, being measured upon the scale *AB* in Fig. 3, will be equal to Venus's parallax in longitude; either on or from the Sun; and this parallax, being always contrary to the position of the place, is eastward as long as the place keeps on the left hand of the axis of the ecliptic, as seen from the Sun; and westward when the place gets to the right hand of the axis of the ecliptic. So that, to all the places which are posited in the hemisphere *EAD* of the disc, at any given time, Venus has an eastern parallax of longitude; but when the Earth's diurnal motion carries the same places into the hemisphere *EBD*, the parallax of Venus is westward.

49. When Venus has a parallax toward the east, as seen from any given place on the Earth's surface, either at the time of her total ingress or beginning of egress, as seen from the Earth's center; add the time answering to this parallax to the time of ingress or egress at the Earth's center, and the sum will be the time thereof, as seen from the given place on the Earth's surface; but when the parallax is westward, subtract the time answering thereto from the time of total ingress or beginning of egress as seen from the Earth's center, and the remainder will be the time as seen from the given place on the surface, so far as it is affected by this parallax.—The reason of this is plain to every one who considers, that an eastern parallax keeps the planet back, and a western parallax carries it forward, with respect to its true place or position, at any instant of time, as seen from the Earth's center.

50. The distance of any given place from the plane of the ecliptic *ECD*, at any hour or part of an hour, being measured on the scale *AB* in Fig. 3, will be \* equal to Venus's parallax in latitude, which is northward from the true line of her path on the Sun as seen from the Earth's

\* The parallax of latitude, strictly speaking, ought to be measured from a plane passing through the center of the Earth's disc, and coincident with that part of Venus's orbit in which she moves during her transit.—But, as such a plane would cut the Earth's surface only  $7\frac{1}{2}$  minutes of a degree south of those places which are cut by the plane of the ecliptic at the beginning of the transit, and about 11 minutes of a degree south of those places which are cut by the plane of the ecliptic at the end of the transit, the difference would scarce be sensible in this projection, and may therefore be neglected; especially as it will not, in fact, amount to half a second of difference in Venus's parallax of latitude on the disc of the Sun.

center,

center, if the given place be on the south side of the plane of the ecliptic; and the contrary, if the given place be on the north side of that plane; that is, the parallax is always contrary to the situation of the place on the Earth's disc, with respect to the plane of the ecliptic, as seen from the Sun.

51. As the path of Venus, or line of her transit, is on the southern hemisphere of the Sun's disc, it is plain that a northern parallax in her latitude will cause her to describe a longer line on the Sun, than if she had no such parallax; and a southern parallax in latitude will cause her to describe a shorter line on the Sun, than if she had no such parallax.—And the longer this line is, the sooner will her total ingress be, and the later will be her beginning of egress: and just the contrary if the line be shorter.—But, to all places situated on the north side of the ecliptic, in the hemisphere *AEB*, the parallax of latitude is south; and to all places situated on the south side of the plane of the ecliptic, in the hemisphere *ADB*, the parallax of latitude is north. Therefore, the line of the transit will be shorter to all places in the hemisphere *AEB*, than it will be as seen from the Earth's center, where there is no parallax at all; and longer to all places in the hemisphere *ADB*. So that the time answering to this parallax must be added to the time of total ingress as seen from the Earth's center, and subtracted from the beginning of egress as seen from the Earth's center, in order to have the true time of total ingress and beginning of egress as seen from places in the hemisphere *AEB*: and just the reverse for places in the hemisphere *ADB*.—It was proper to mention these circumstances, for the reader's more easily conceiving the reason of applying the times answering to the parallaxes of longitude and latitude in the subsequent part of this article: for it is their sum in some cases, and their difference in others, which being applied to the times of total ingress and beginning of egress as seen from the Earth's center, that will give the times thereof as seen from the given places on the Earth's surface.

52. The angle which the Sun's semidiameter subtends, as seen from the Earth, at all times of the year, has been so well ascertained by late observations, that we can make no doubt of its being  $15' 50''$  on the day of the transit; and Venus's latitude has also been so well ascertained at many different times of late, that we have very good reason to believe it will be  $9' 43''$  south of the Sun's center, at the time of her conjunction with the Sun.—If then, her semidiameter at that time be  $37\frac{1}{2}''$  (as mentioned by Dr. HALLEY, it appears by the projection (Fig. 2.) that her total ingress on the Sun as seen from the Earth's center, will be at 28 minutes after 11 in the morning (§ 40.) and her beginning of egress from



from the Sun will be 20 minutes after VIII, according to the time reckoned at *London*.

53. As the total ingress will not be visible at *London*, we shall not at present trouble the reader about Venus's parallax at that time.—But by projecting the situation of *London* on the Earth's disc (Fig. 4.) for the time when the egress begins, we find it will then be at *l*, as seen from the Sun.

Draw *ld* parallel to the ecliptic *ACB*, and *lu* perpendicular to it: the former is Venus's eastern parallax in longitude at her beginning of egress, and the latter is her southern parallax in latitude at that time. Take these in your compasses, and measure them on the scale *AB* (Fig. 3.) and you will find the parallax in longitude to be  $13\frac{1}{2}''$ , and the parallax in latitude to be  $19\frac{1}{2}''$ .

54. As Venus's true motion on the Sun is at the rate of 4 minutes of a degree in 60 minutes of time (See N<sup>o</sup> XI. of § 31.) say, as 4' is to 60 minutes, so is  $13\frac{1}{2}''$  to 3 minutes 23 seconds of time; which being added to VIII hours 20 minutes (because this parallax is eastward, § 49.) gives VIII hours 23 minutes 23 seconds, for the beginning of egress at *London*, as affected only by this parallax.—But, as Venus has a southern parallax of latitude at that time, her beginning of egress will be sooner; for this parallax shortens the line of her visible transit at *London*.

55. As this last mentioned parallax is  $19\frac{1}{2}''$  south, add it to Venus's latitude  $9' 43''$ , and the sum will be  $10' 2\frac{1}{2}''$ ; which is to be taken from the scale in Fig. 1. and set from *t* to *L* in Fig. 2. And then, if it be drawn parallel to *tl*, it will terminate at the point *p* in the arc *T*, where Venus's center will be at the beginning of her egress as seen from *London* \*.—But as her center is at *l* when her egress begins as seen from the Earth's center, take *Lp* in your compasses, and setting that extent from *t* towards *l* on the central transit-line, you will find it to be 5 minutes shorter than *tl*: therefore subtract 5 minutes from VIII hours 23 minutes 23 seconds, and there will remain VIII hours 18 minutes 23 seconds for the visible beginning of egress in the morning at *London*.

56. At V hours 24 minutes (which is the middle of the transit as seen from the Earth's center) *London* will be at *L* on the Earth's disc, (Fig. 4.) as seen from the Sun. The parallax of longitude *La* is then  $17\frac{1}{2}''$ ; by

\* The reason why the lines *oLp*, *aBb*, *ct*, and *tb*, which are the visible transits at *Dondon*, the *Ganges* mouth, *Bencoolen*, and *St. Helena*, are not parallel to the central transit-line *ktl*, is because the parallaxes in latitude are different at the times of ingress and egress, as seen from each of these places. The method of drawing these lines will be shewn by and by.

which, working as above directed, we find the middle of the transit as seen from *London*, to be at V hours 28 minutes 15".—This is not affected by the parallax of latitude *Lt*.—But *Lt* measures  $24\frac{1}{2}''$  on the scale *AB* (Fig. 3.) therefore take  $24\frac{1}{2}''$  from the scale in Fig. 1. and set it from *t* to *L*, on the axis of Venus's path in Fig. 2. and laying a ruler to the point *L*, and the above found point of egress *p*, draw *oLp* for the line of the transit as seen from *London*.

57. The eastern mouth of the river *Ganges* is 89 degrees east from the meridian of *London*; and therefore, when the time at *London* is 28 minutes after II in the morning, (§ 40.) it is 24 minutes past VIII in the morning (by § 47.) at the mouth of the *Ganges*; and when it is 20 minutes past VIII in the morning at *London* (§ 40.) it is 16 minutes past II in the afternoon at the *Ganges*. Therefore, by projecting that place upon the Earth's disc, as seen from the Sun, it will be at *G* (in Fig. 4.) at the time of Venus's total ingress, as seen from the Earth's center, and at *g* when her egress begins.

Draw *Ge* parallel to the ecliptic *ACB*, and *gC* coincident with it; and measure them on the scale *AB* in Fig. 3. the former will be  $22\frac{1}{2}''$  for Venus's eastern parallax in longitude, at the abovementioned time of her total ingress, and the latter will be  $16\frac{1}{4}''$  for her western parallax in longitude at the time when her egress begins.—The first parallax gives 5 minutes 34 seconds of time (by the analogy in § 54.) to be added to VIII hours 24 minutes, and the latter parallax gives 4 minutes 11 seconds to be subtracted from II hours 16 minutes, by which we have VIII hours 29 minutes 34 seconds, for the time of total ingress as seen from the banks of the *Ganges*, and II hours 11 minutes 49 seconds for the beginning of egress.

Draw *Gf* perpendicular to the ecliptic *ACB*, and by measurement on the scale *AB* (Fig. 3.) it will be found to contain  $6\frac{1}{2}''$ ; which being taken from the scale in Fig. 1. and set off southward from the point of total ingress *k*, (in Fig. 2. as seen from the Earth's center) parallel to the axis of Venus's path, it will fall into the point *c* on the arc *N*.—Draw *Ct* (which might be parallel to the central transit-line *ktl*) and taking the extent *tc* in your compasses, and applying it from *t* towards *k*, you will find it to fall a minute short of *k*; which shews that Venus's parallax in latitude shortens the beginning of the line of her visible transit at the *Ganges* by one minute of time. Therefore, as this makes the visible ingress a minute later, add one minute to the above VIII hours 29 minutes 34 seconds, and it gives VIII hours 30 minutes 34 seconds for the time of total ingress, in the morning, as seen from the eastern mouth of the *Ganges*. At the beginning of egress there is no parallax



of latitude, and therefore the time is II hours 11 minutes 49 seconds in the afternoon.

58. It appears by Fig. 4. that the mouth of the *Ganges* will be but a very little to the south of the plane of the ecliptic at the middle of the transit, and directly in that plane of the beginning of egress: therefore, if from *c* (in Fig. 2.) the point of total ingress, the line *ctl* be drawn, it will be the visible line of the transit at the mouth of the *Ganges*.

59. *Bencoolen* is 102 degrees east from the meridian of *London*, and therefore, when the time is 28 minutes past II in the morning at *London*, it is 16 minutes past IX in the morning at *Bencoolen*, and when it is 20 minutes past VIII in the morning at *London*, it is 8 minutes past III in the afternoon at *Bencoolen*. Therefore, in Fig. 4, *Bencoolen* will be at *B* at the time of Venus's total ingress as seen from the Earth's center; and at *b* when her egress begins.

Draw *Bi* and *bk* parallel to the ecliptic *ACB*, and measure them on the scale; the former will be found to be 21" for Venus's eastern parallax in longitude at the time of her total ingress, and the latter to be 22" for her western parallax in longitude when her egress begins, as seen from the Earth's center. The first of these parallaxes gives 5 minutes 15 seconds (by the analogy in § 54.) to be added to IX hours 16 minutes, and the latter parallax gives 5 minutes 30 seconds to be subtracted from III hours 8 minutes; whence we have IX hours 21 minutes 15 seconds for the time of total ingress at *Bencoolen*; and III hours 2 minutes 30 seconds for the time when the egress begins there, as affected by these two parallaxes.

95. Draw *Bv* and *bm* perpendicular to the ecliptic *ACB*, and measure them on the scale *AB*: the former will be 8½" for Venus's northern parallax in latitude, as seen from *Bencoolen* at the time of her total ingress; and the latter will be 12" for her northern parallax in latitude when her egress begins. Take these parallaxes from the scale in Fig. 1. in your compasses, and set them off above the central transit-line, perpendicular to the axis of Venus's path; the former from the left-hand of *k* (Fig. 2.) to *a* in the arc *N*, and the latter from the right-hand of *l* to *b* in the arc *T*; and draw *aBb* for the line of Venus's transit as seen from *Bencoolen*: the center of Venus being at *a*, as seen from *Bencoolen*, at the moment of her total ingress; and at *b* at the moment when her egress begins.

But as seen from the Earth's center, the center of Venus is at *k* in the former case, and at *l* in the latter: so that we find the line of the transit is longer as seen from *Bencoolen* than as seen from the Earth's

center, which is the effect of Venus's northern parallax in latitude.—Take *Ba* in your compasses, and setting that extent from *t* toward *g* on the central transit-line, you'll find it will reach two minutes beyond *k* thereon: and taking the extent *Bb* in your compasses, and setting it from *t* towards *w* on the central transit-line, it will be found to reach  $2\frac{1}{2}$  minutes beyond *l* thereon. Consequently, if we subtract 2 minutes from IX hours 21 minutes 15 seconds (above found) we have IX hours 19 minutes 15 seconds, in the morning, for the time of total ingress as seen from *Bencoolen*: and if we add 2 minutes 30 seconds to the above-found III hours 2 minutes 30 seconds, we shall have III hours 5 minutes 0 seconds after noon, for the time when the egress begins as seen from *Bencoolen*.

60. The whole duration of the transit, from total ingress to beginning of egress, as seen from the Earth's center, is 5 hours 52 minutes (by § 40) but the whole duration from total ingress to beginning of egress, as seen from *Bencoolen*, is only 5 hours 45 minutes 45 seconds; which is 6 minutes 15 seconds less than as seen from the Earth's center: and this 6 minutes 15 seconds is the whole effect of the parallaxes (both in longitude and latitude) on the duration of the transit at *Bencoolen*.

But the duration as seen from the banks of the *Ganges*, from ingress to egress, is still less; for it is only 5 hours 41 minutes 15 seconds: which is 10 minutes 45 seconds less than as seen from the Earth's center, and 4 minutes 30 seconds less than as seen from *Bencoolen*.

61. The island of *St. Helena* (to which only a small part of the transit is visible at the end) will be at *H* (as in Fig. 4.) when the egress begins as seen from the Earth's center. And since the middle of that island is  $6^{\circ}$  west from the meridian of *London*, and the said egress begins when the time at *London* is 20 minutes past VIII in the morning, it will then be only 56 minutes past VII in the morning at *St. Helena*.

Draw *Hn* parallel to the ecliptic *ACB*, and *Ho* perpendicular to it; and by measuring them on the scale *AB*, (Fig. 3.) the former will be found to amount to  $27''$  for Venus's eastern parallax in longitude, as seen from *St. Helena*, when her egress begins as seen from the Earth's center; and the latter to be  $10''$  for her northern parallax in latitude at that time.

By the analogy in § 54, this parallax of longitude gives 6 minutes 45 seconds of time; which being added (on account of its being eastward) to VII hours 56 minutes, gives VIII hours 2 minutes 45 seconds for the beginning of egress at *St. Helena*, as affected by this parallax.—But  $10''$  of parallax in latitude (applied as in the case of *Bencoolen*)



*coolen*) lengthens out the end of the tranfit-line by 2 minutes 24 seconds ; which being added to VIII hours 2 minutes 45 seconds, gives VIII hours 5 minutes 9 seconds for the beginning of egress as seen from *St. Helena*.

61. We shall now collect the abovementioned times into a small table, that they may be seen at once, as follows. *M* signifies morning, *A* afternoon.

|                         | Total ingrefs.       |    |    | Beg. of egress. |    |    | Duration. |    |    |
|-------------------------|----------------------|----|----|-----------------|----|----|-----------|----|----|
|                         | H.                   | M. | S. | H.              | M. | S. | H.        | M. | S. |
| The Earth's center      | II                   | 28 | 0  | VIII            | 20 | 0  | 5         | 52 | 0  |
| <i>London</i> - - -     | Invisible. <i>M.</i> |    |    | VIII            | 18 | 23 | —         | —  | —  |
| At The Ganges mouth     | VIII                 | 30 | 34 | II              | 11 | 49 | 5         | 41 | 15 |
| <i>Bencoolen</i> - - -  | IX                   | 19 | 15 | III             | 5  | 0  | 5         | 45 | 45 |
| <i>St. Helena</i> - - - | Invisible. <i>M.</i> |    |    | VIII            | 5  | 9  | —         | —  | —  |

62. The times at the three last mentioned places are reduced to the meridian of *London*, by subtracting 5 hours 56 minutes from the times of ingress and egress at the *Ganges*; 6 hours 48 minutes from the times thereof at *Bencoolen*; and adding 24 minutes to the time of beginning of egress at *St. Helena*: and being thus reduced, they are as follow.

|                                      | Total ingrefs.       |    |    | Beg. of egress. |    |    |                          |
|--------------------------------------|----------------------|----|----|-----------------|----|----|--------------------------|
|                                      | H.                   | M. | S. | H.              | M. | S. |                          |
| Times at { <i>Ganges</i> mouth -     | II                   | 34 | 34 | VIII            | 15 | 49 | } Durations<br>as above. |
| <i>London</i> { <i>Bencoolen</i> - - | II                   | 31 | 15 | VIII            | 17 | 0  |                          |
| for { <i>St. Helena</i> - -          | Invisible. <i>M.</i> |    |    | VIII            | 29 | 9  |                          |

63. All this is on supposition, that we have the true longitudes of the three last mentioned places, that the Sun's horizontal parallax is  $12\frac{1}{2}''$ , that the true latitude of Venus is given, and that her semi-diameter will subtend an angle of  $37\frac{1}{2}''$  on the Sun's disc.

As for the longitudes we must suppose them true, until the observers ascertain them, which is a very important part of their business; and without which they can by no means find the interval of absolute time that elapseth between either the ingress or egress, as seen from any two given places: and we depend much more upon this elapse than upon the whole contraction of duration at any given place, as it will undoubtedly afford a surer basis for determining the Sun's parallax.

64. I have good reason to believe, that the latitude of Venus, as given in § 31, will be found by observation to be accurate; but that the time

time of conjunction there mentioned will be found to anticipate the true time by almost 5 minutes; that Venus's semidiameter will subtend an angle of no more than  $31''$  on the Sun's disc, and that the middle of her transit as seen from the Earth's center will be at 29 minutes after V in the morning, as reckoned by the equal time at *London*.

65. By adapting the abovementioned projections to these last numbers, supposing the Sun's horizontal parallax to be  $12\frac{1}{2}''$ , and reducing all the times to the meridian of *London*, I find these times to be as follow:

|                     |                       | Total ingrefs. |    |    | Beg. of egress. |    |    | Duration. |    |    |
|---------------------|-----------------------|----------------|----|----|-----------------|----|----|-----------|----|----|
|                     |                       | H.             | M. | S. | H.              | M. | S. | H.        | M. | S. |
| At                  | The Earth's center -  | II             | 30 | 0  | VIII            | 28 | 0  | 5         | 58 | 0  |
|                     | <i>London</i> — —     | Invisible.     |    |    | VIII            | 26 | 37 | —         | —  | —  |
|                     | <i>Ganges mouth</i> — | II             | 37 | 0  | VIII            | 24 | 20 | 5         | 47 | 20 |
|                     | <i>Bencoolen</i> —    | II             | 34 | 25 | VIII            | 25 | 50 | 5         | 51 | 25 |
|                     | <i>St. Helena</i> —   | Invisible.     |    |    | VIII            | 36 | 15 | —         | —  | —  |
| All in the morning. |                       |                |    |    |                 |    |    |           |    |    |

66. Subtract VIII hours 26 minutes 37 seconds, the time when the egress begins at *London*, from VIII hours 36 minutes 15 seconds, the time reckoned at *London* when the egress begins at *St. Helena*, and there will remain 9 minutes 38 seconds (or 578 seconds) for the difference, or elapse, in absolute time, between the beginning of egress as seen from these two places.

Divide this elapse of 578 seconds by the Sun's parallax  $12\frac{1}{2}''$ , and the quotient will be 46 seconds, and a small fraction. So that for each second of a degree in the Sun's horizontal parallax (supposing it to be  $12\frac{1}{2}''$ ) there will be a difference or elapse of 46 seconds of absolute time between the beginning of egress as seen from *London*, and as seen from *St. Helena*: and consequently, 23 seconds of time for every half second of the Sun's parallax;  $12\frac{1}{2}$  seconds of time for every fourth part of a second of the Sun's parallax;  $6\frac{1}{4}$  seconds of time for the eighth part of a second of the Sun's parallax, and full 3 seconds for a sixteenth part of a second of the Sun's parallax.

For, in such a small angle as that of the Sun's parallax, the arc is equal both to its sine and to its tangent: and therefore, the quantity of this parallax is in direct proportion to the absolute difference in the time of egress arising from it, at different parts of the Earth.

65. Therefore,



65. Therefore, when this difference is ascertained by good observations, made at different places, and compared together, the true quantity of the Sun's parallax will be very nearly determined. For, since it may be presumed that the beginning of egress can be observed within 2 seconds of its real time, the Sun's parallax may be then found within the 23d part of a second of its true quantity; and consequently, his distance may be found within a 287th part of the whole, provided his parallax be not less than  $12\frac{1}{2}''$ ; for 23 times  $12\frac{1}{2}$  is 287.5.

67. But since Dr. HALLEY has assured us that he had observed the two internal contacts of the planet Mercury with the Sun's edge, so exactly as not to err one second in the time thereof, we may well imagine that the internal contacts of Venus with the Sun may be observed with as great accuracy. For, although the real motion of Mercury is quicker than the motion of Venus, yet Venus is so much nearer the Earth than Mercury is in such transits, that Venus's apparent motion on the Sun is very near as quick as Mercury's; and as Venus is a much bigger planet than Mercury, and also much nearer the Earth at the time of the transit than ever Mercury is, a greater part of the Sun's limb will seem to be instantaneously broke by the contact of Venus, than by the contact of Mercury; and therefore her contact will be so much the more readily perceived. So that we may hope to have the absolute interval between the moments of her beginning of egress as seen from *London* and from *St. Helena* true to a second of time; and if so, the Sun's parallax may be determined to the 46th part of a second, provided it be not less than  $12\frac{1}{2}''$ ; and consequently his distance may be found, within its 570th part, for 46 times  $12\frac{1}{2}$  is 575: which is still nearer the truth than Dr. HALLEY expected it might be found, by observing the whole duration of the transit in the *East-Indies* and at *Port-Nelson*. So that our present Astronomers have judiciously resolved to improve the Doctor's method, by taking only the interval between the absolute times of its ending at different places. And if the Sun's parallax be only  $10\frac{1}{2}''$ , the interval between the time at *St. Helena* and at *London* will be 485 seconds, which divided by  $10\frac{1}{2}$ , gives full 46 seconds; which will determine the Sun's distance within its 480th part; for 46 times  $10\frac{1}{2}$  is 485.—If the Sun's parallax be greater or less than either of the above assumed quantities, the difference between the beginning of egress at *London* and at *St. Helena* will be greater or less than the above number of seconds accordingly.

68. I have calculated the following table, to shew what the Sun's real distance must be, in English miles, for every 10th part of a second of his parallax, from  $10''$  to  $12\frac{1}{2}''$ ; stating the diameter of the Earth at 3985 English miles.

69. There will be a much greater difference between the absolute times of egress at *St. Helena* and the northern parts of *Russia*, than between these times at *St. Helena* and *London*. The difference between them at *Tobolsk* in *Siberia* and at *St. Helena* will be  $11\frac{1}{2}$  minutes: at *Archangel* it will be but about 40 seconds less than at *Tobolsk*, and only a minute and a quarter less at *Petersburg*, even if the Sun's parallax be no more than  $10\frac{1}{2}''$ . At *Wardbus* the same advantage would nearly be gained as at *Tobolsk*: but if the observers could go still farther to the east, as to *Yakoutsk* in *Siberia*, the advantage would be still greater; for, as Mr. DE L'ISLE very justly observes, in a memoir presented to the French king with his map of the transit, the difference of time between Venus's egress from the Sun at *Yakoutsk* and at the *Cape of Good Hope* will be  $13\frac{1}{2}$  minutes.

70. The absolute time of the beginning of egress is very nearly the same both at the *Cape of Good Hope* and *St. Helena*. Therefore, if we have good observations from *St. Helena*, and from *Petersburg*, or *Tobolsk*; but especially from *Yakoutsk*, where there will be a difference of 810 seconds of time (which is 325 more than between *St. Helena* and *London*) even upon a solar parallax no greater than  $10\frac{1}{2}''$ , this would give 77 seconds of time for every second of parallax, and consequently would ascertain the Sun's parallax to the 77th part of a second of the truth, and his distance to within the 800th part of what it really is; for 77 times  $10\frac{1}{2}$  is 808 $\frac{1}{2}$ .

71. This method requires that the longitude of each place of observation be ascertained to the greatest degree of nicety, and that each observer's clock be exactly regulated to the equal time at his place: for without

| Sun's parallax. | His distance in English miles. |
|-----------------|--------------------------------|
|-----------------|--------------------------------|

|        |            |
|--------|------------|
| "      |            |
| 10. -  | 82 196 604 |
| 10.1 - | 81 541 135 |
| 10.2 - | 80 885 666 |
| 10.3 - | 80 230 198 |
| 10.4 - | 79 574 729 |
| 10.5 - | 78 919 260 |
| 10.6 - | 78 263 791 |
| 10.7 - | 77 608 322 |
| 10.8 - | 76 952 854 |
| 10.9 - | 76 297 385 |
| 11. -  | 75 641 916 |
| 11.1 - | 74 986 447 |
| 11.2 - | 74 330 978 |
| 11.3 - | 73 675 509 |
| 11.4 - | 73 020 041 |
| 11.5 - | 72 364 572 |
| 11.6 - | 71 709 103 |
| 11.7 - | 71 053 634 |
| 11.8 - | 70 398 166 |
| 11.9 - | 69 742 697 |
| 12. -  | 69 087 228 |
| 12.1 - | 68 431 759 |
| 12.2 - | 67 776 290 |
| 12.3 - | 67 120 822 |
| 12.4 - | 66 465 353 |
| 12.5 - | 65 809 884 |

Common difference } 655 469  
for  $\frac{1}{77}$  of  $1''$  of paral.



without these particulars, it would be impossible for the observers to reduce the times to those which are reckoned under any given meridian; and without reducing the observed times of egress at different places to the time at some given place, the absolute time that elapseth between the egress at one place and at another could not be found. But every one knows, that the longitude can be accurately found by observing the eclipses of Jupiter's satellites; and that a true meridian, for regulating the clock, may be had by observing when any given star, within 20 or 30 degrees of the pole, is stationary with regard to its azimuth, on the east and west sides of the pole: the pole itself being the middle point between these two stationary positions of the star. And it is not material for the observers to know exactly either the true angular measure of the Sun's diameter or of Venus's, in this case: for whatever their diameters be, it will make no difference as to the observed interval between the same contact, as seen from different places.

72. The scale *AB* (Fig. 3. of Plate III.) may be divided into any given number of equal parts, answering to any assumed quantity of Venus's horizontal parallax from the Sun (which is always the difference between the horizontal parallax of Venus and that of the Sun) provided its whole length be equal to the semidiameter of the Earth's disc in Fig. 4.—Thus, if we suppose Venus's horizontal parallax from the Sun to be only 26" (instead of 31") in which case the Sun's horizontal parallax must be 10".3397, as in § 13, the rest of the projection will answer to that scale: as *CD*, which contains only 26 equal parts, is the same length as *AB*, which contains 31. And by working in all other respects as taught from § 46 to § 57, you will find the times of total ingress and beginning of egress; and consequently, the duration of the transit at any given place, which must result from such a parallax.

73. In the former edition of this work (pag. 43.) I mentioned a large projection of this transit, in which the Sun's diameter is 30 inches. But, as that projection is delineated on pasteboard, which lies not so flat as I could wish, I have now made a projection of the same transit upon a deal board covered on both sides with paper, which I find answers the purpose much better. In this, the horary minutes on the transit-line are so large, that I can easily find the time by measurement, within 10 seconds: for the Sun's diameter is full  $37\frac{1}{2}$  inches.

This projection is according to the following elements. 1. That the Sun's horizontal parallax is  $10\frac{1}{2}$ ". 2. That the true conjunction of the Sun and Venus will be at 50 minutes 32 seconds after V in the morning  
F. at

at London. 3. That the Sun's semidiameter is then  $15' 50''$ . 4. That the semidiameter of Venus will measure  $31''$  on the Sun's disc. 5. That the geocentric latitude of Venus is  $9' 43''$  south. 6. That the true motion of Venus on the Sun is  $4'$  of a degree in each hour of her transit, as seen from the Earth's center. And, 7. That the angle which the Earth's axis makes with the axis of Venus's orbit is  $14^{\circ}\frac{1}{2}$ , as seen from the Sun.

According to these elements, the times of first contact, total ingress, middle of the transit, beginning of egress, and last contact of Venus with the Sun, as seen from the Earth's center, from *Tobolsk*, from the *Ganges* mouth, from *London*, *Bencoolen*, and *St. Helena*, are as expressed in the following table.—How near they are to the truth, can be determined only by observation; and to that test I willingly submit them.

74. In projections of this kind, it may be easily conceived, that a right line passing continually through the center of Venus, and a given point of the Earth, and produced to the Sun's disc, will mark the path of Venus on the Sun as seen from the given point of the Earth: and in this there are three cases. 1. When the given point is the Earth's center, at which there is no parallax, either in longitude or latitude. 2. When the given point is one of the poles, where there is no parallax of longitude; but a parallax of latitude, whose quantity is easily determined, by letting fall a perpendicular from the pole upon the plane of the ecliptic (or more properly on a plane which passes through the Earth's center, and being produced to the Sun, coincides with the line of Venus's path thereon) and setting off the parallax of latitude on this perpendicular.—Here, the polar transit-lines will be parallel to the central; as the poles have no motion arising from the Earth's diurnal rotation. 3. The last case is, when the given point of the Earth is any point of its surface whose latitude is less than 90 degrees: then there is a parallax in latitude proportional to the perpendicular let fall upon the above said plane, from the given point; and a parallax in longitude proportional to the perpendicular let fall upon the axis of that plane, from the said given point. And the effect of this last will be to alter the transit-line, both in position and length; and will prevent its being parallel to the central transit-line, unless when its axis and the axis of the Earth coincide, as seen from the Sun; which is a thing that may not happen in many ages.



The times of the beginning, middle, end, and duration of the transit of Venus, as seen at the several places below.

The times of the transit as reckoned at these places.

The same times as reckoned at London.

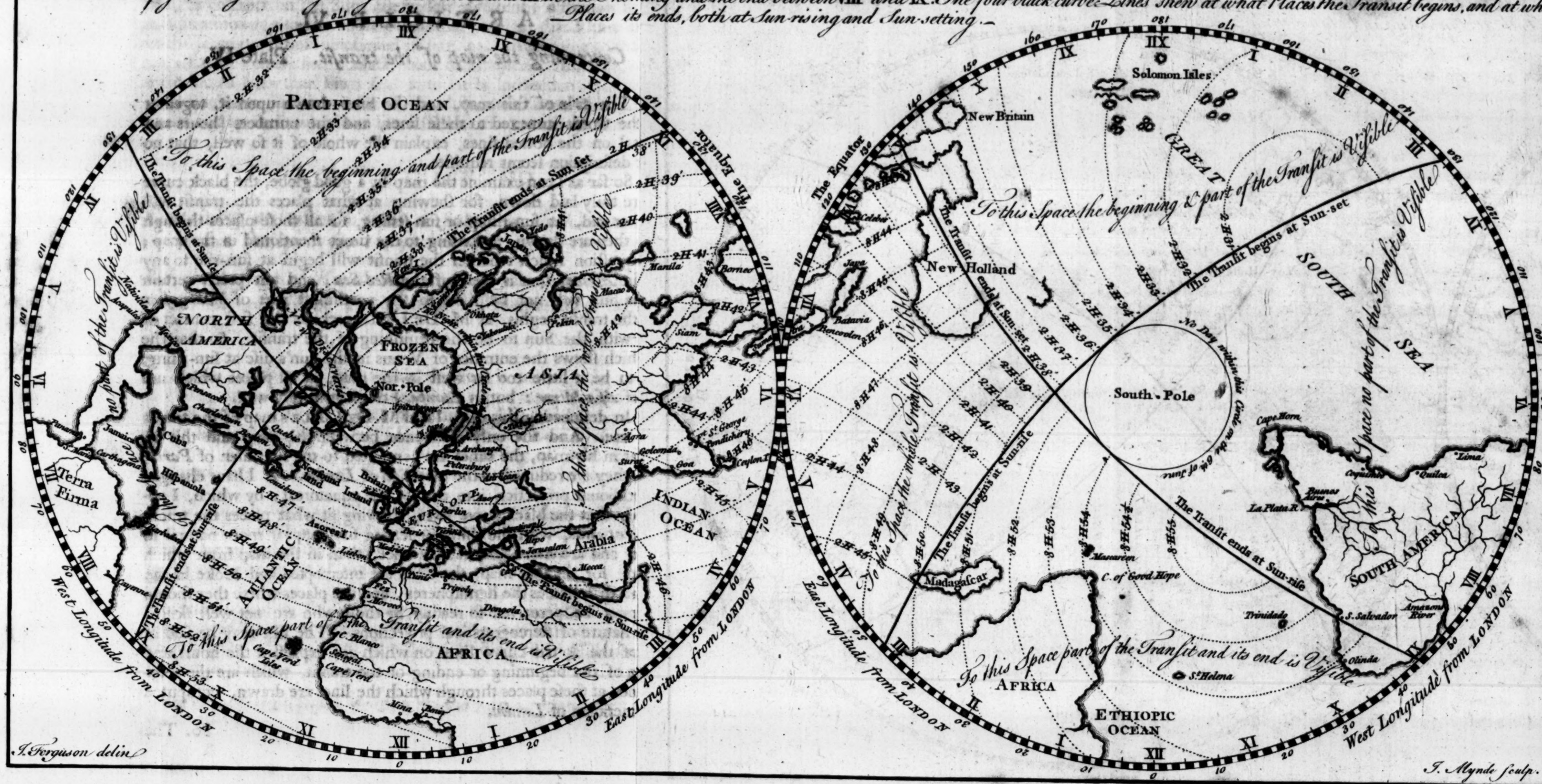
| Places.                         | Tobolsk.                                  | Ganges mouth.                             | Brussels.                                 | St. Helena.                               | Tobolsk.                                  | Ganges mouth.                             | London.                                   | Brussels.                                 | St. Helena.                               |
|---------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
| Times.                          | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  | H. M. S.                                  |
| First contact                   | VII 3 58 M                                | VIII 12 26 M                              | IX 2 13 M                                 | I 49 31 M                                 | II 15 58 M                                | II 16 26 M                                | II 15 37 M                                | II 14 13 M                                | II 13 31 M                                |
| Central ingress                 | VII 13 55 M                               | VIII 22 14 M                              | IX 11 57 M                                | I 59 46 M                                 | II 25 55 M                                | II 26 14 M                                | II 25 45 M                                | II 23 57 M                                | II 23 46 M                                |
| Total ingress                   | VII 23 53 M                               | VIII 32 2 M                               | IX 21 43 M                                | I 10 1 M                                  | II 35 53 M                                | II 36 2 M                                 | II 35 54 M                                | II 33 43 M                                | II 34 1 M                                 |
| Middle                          | X 17 40 M                                 | XI 26 25 M                                | 0 18 3 A                                  | V 10 32 M                                 | V 29 40 M                                 | V 30 25 M                                 | V 31 25 M                                 | V 30 3 M                                  | V 34 32 M                                 |
| Beg. of egress                  | I 11 28 A                                 | II 20 49 A                                | III 14 26 A                               | VIII 11 2 M                               | VIII 23 28 M                              | VIII 24 49 M                              | VIII 26 57 M                              | VIII 26 26 M                              | VIII 34 35 M                              |
| Central egress                  | I 21 20 A                                 | II 30 37 A                                | III 24 11 A                               | VIII 20 53 M                              | VIII 33 20 M                              | VIII 34 37 M                              | VIII 36 51 M                              | VIII 36 11 M                              | VIII 44 53 M                              |
| Last contact                    | I 31 12 A                                 | II 40 25 A                                | III 33 56 A                               | VIII 30 45 M                              | VIII 43 12 M                              | VIII 44 25 M                              | VIII 46 45 M                              | VIII 45 56 M                              | VIII 54 45 M                              |
| Duration                        | From first to last contact                | From first to last contact                | From first to last contact                | From first to last contact                | From first to last contact                | From first to last contact                | From first to last contact                | From first to last contact                | From first to last contact                |
| at these places                 | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    | From central ingress to central egress    |
|                                 | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress | From total ingress to beginning of egress |
|                                 | 6 27 14                                   | 6 28 59                                   | 6 31 8                                    | 6 31 8                                    | 6 27 14                                   | 6 28 59                                   | 6 31 8                                    | 6 31 43                                   | 6 41 14                                   |
|                                 | 6 7 25                                    | 6 8 23                                    | 6 11 6                                    | 6 11 6                                    | 6 7 25                                    | 6 8 23                                    | 6 11 6                                    | 6 12 14                                   | 6 21 7                                    |
|                                 | 5 47 35                                   | 5 48 47                                   | 5 51 3                                    | 5 51 3                                    | 5 47 35                                   | 5 48 47                                   | 5 51 3                                    | 5 52 43                                   | 6 1 1                                     |
| As seen from the Earth's center | Total ingress                             | II 30 0                                   | Duration                                  | From first to last contact                | From central ingress to central egress    | From total ingress to beginning of egress | H. M. S.                                  | True time of conjunction                  | V 32 seconds in the morning.              |
|                                 | Middle                                    | V 29 0                                    |                                           |                                           |                                           |                                           | 6 38 0                                    |                                           |                                           |
|                                 | Begin. of egress                          | VIII 28 0                                 |                                           |                                           |                                           |                                           | 6 18 0                                    |                                           |                                           |
|                                 |                                           |                                           |                                           |                                           |                                           |                                           | 58 0                                      |                                           |                                           |

75. It appears by § 65 and 66, that if the Sun's horizontal parallax be  $12\frac{1}{2}''$ , the absolute difference between the times of Venus's beginning of egress from the Sun at *London* and *St. Helena*, must be 9 minutes 38 seconds (or 578 seconds) of time: and by the table in page 43, that if the Sun's horizontal parallax be only  $10\frac{1}{2}''$ , the absolute difference of beginning of egress at *London* and *St. Helena* must be 8 minutes 5 seconds (or 485 seconds): so that for every 2 seconds of difference in the Sun's parallax, there will be a difference of 83 seconds of time in the interval between the egress at these two places; and consequently  $41\frac{1}{2}$  seconds of time for every second in the difference of parallax, and so on.—But as these numbers are only deduced from projection, and not from computation, they cannot be so much depended upon, as if they had been computed arithmetically; which I confess I have not done.

76. In the year 1769, there will be a transit of Venus over the Sun on the third of June, much better for investigating the Sun's parallax by Dr. HALLEY's method than this transit is: but no part of it will be visible in *Britain*. For the time of Venus's conjunction with the Sun will be a quarter after X in the evening at *London*, at which time it will be near midnight at *Torneo* in *Lapland*: but as the Sun will then be only 2 degrees below the horizon of that place, the whole of the transit will be visible there, excepting only a little part about the middle, which is of no consequence.—At that time the Sun will be vertical in the *Great South Sea* in north latitude  $22\frac{1}{2}$  degrees, and west longitude from the meridian of *London* 154 degrees. At that time, it will be about half an hour past X in the *Solomon Isles*. If proper observers are sent to *Torneo*, and to some of these islands, they will have the like advantage as was mentioned by Dr. HALLEY, with regard to the motion of places about the *Ganges* and the motion of *Port-Nelson*. For the *Solomon Isles* will have a contrary motion to that of Venus, which will accelerate her motion on the Sun as seen from them; and *Torneo* will have a motion the same way as that of Venus, which will retard her motion on the Sun as seen from it. Moreover, as seen from *Torneo*, Venus will have a southern parallax of latitude on the Sun, which will prolong the line of her transit, as it will be on the northern hemisphere of the Sun; and as seen from the *Solomon Isles* she will have a northern parallax of latitude, which will contract the length of the transit-line: and consequently, there will be almost the greatest possible difference in the duration of the transit at these two places. It is therefore to be hoped that neither cost nor labour



A MAP of the EARTH, Upon which are marked the Hours and Minutes of true Times of the Entrance and Exit of VENUS, in its Passage over the SUN'S DISC. June 6<sup>th</sup> 1761. The Times are computed to the Meridian of LONDON, and that which is expressed upon each dotted line shews when the Transit begins or ends at all those Places which the same Line passes through. The beginning is between II and III in the Morning and the end between VIII and IX. The four black curve Lines shew at what Places the Transit begins, and at what Places its ends, both at Sun-rising and Sun-setting.





labour will be spared in duly observing that transit, as there will not be such another opportunity in 100 years afterward.

## ARTICLE VI.

Concerning the map of the transit. Plate IV.

77. The title of this map, and the lines drawn upon it, together with the words annexed to these lines, and the numbers [hours and minutes] on the dotted lines, explain the whole of it so well, that no farther description seems requisite.

78. So far as I can examine the map by a good globe, the black curve lines are truly laid down, for shewing at what places the transit will begin, or end, at sun-rising or sun-setting, to all those places through which they are drawn, according to the times mentioned in the map; but I question much whether the transit will begin at sun-rise to any place in *Africa*, that is west of the *Red-Sea*; and am pretty certain that the Sun will not be risen to the northmost part of *Madagascar* when the transit begins, as M. DE L'ISLE reckons the first contact of Venus with the Sun to be the beginning of the transit. So that the line which shews the entrance of Venus in the Sun's disc at sun-rising, seems to be a little too far west in the map, at all places which are south of *Asia Minor*: but in *Europe*, I think it is very well.

79. In delineating this map, I had M. DE L'ISLE's map of the transit before me. And the only difference between his map and this is, 1. That in his map, the times are computed to the meridian of *Paris*; in this, they are reduced to the meridian of *London*. 2. I have changed his meridional projection into that of the equatoreal; by which, I apprehend, that the black curve lines, shewing at what places the transit begins, or ends, with the rising or setting sun, appear more natural to the eye, and are more fully seen at once, than in the map from which I copied: for, in that map, the lines are interrupted and broke in the meridian that divides the hemispheres; and the places where they should join cannot be perceived so readily by those who are not well skilled in the nature of stereographical projections.—The like may be said of many of the dotted curve lines on which are expressed the hours and minutes of the beginning or ending of the transit, which are the absolute times at these places through which the lines are drawn, computed to the meridian of *London*.

80. The



80. The total exit of Venus from the Sun, as seen from all the places for which I have projected it, comes within a minute of the time shewn for the like places in the map; but the times of her first contact, or entrance on the Sun, are widely different; although the map is accommodated to the same parallax of the Sun that I have assumed in the large projection mentioned in pag. 41. According to the map; the time of Venus's first contact, both at *Tobolsk* and *Bencoolen*, is about 28 minutes later than I can find it to be by projection: and as I am quite unable to find the reason of this difference, I must leave it to be found out by those who have more skill in this branch of science.

## A R T I C L E VII.

*Containing an extract from a paper in the Connoissance  
des Temps \* for the year 1761, titled thus:*

*Of the passage of Venus on the Sun's disc, to be observed  
the 6th of June 1761, and the importance of that  
phenomenon.*

The conjunction of Venus with the Sun is actually the most interesting, as well as the most uncommon appearance, that the heavens present to us. For more than a century past it has been predicted, as to happen in the year 1761; Astronomers have been extolling the use that may be made of it, and exhorting all who shall have the good luck to see it to profit as much as possible by so famous an observation.

And indeed, what would not one undertake in the prospect of this rare phenomenon? whose advantages once let slip, could not be retrieved by any effort of genius, by the most unwearied study, or even by the encouragement of the greatest princes. But as it will be necessary, if we would make a proper use of this transit, that it be observed in *America* and in the *East-Indies*, we found ourselves obliged to give the following account of it; earnestly recommending it to the consideration of all persons capable of lending their assistance in the present inquiry.

\* The author of this paper is *M. De la Lande* of the Royal Academy of Sciences at *Paris*.

*Kepler* having, from *Tycho's* observations, composed his *Rudolphine Tables*, saw very well that Mercury and Venus must sometimes pass over the disc of the Sun: and accordingly gave notice of two transits of Venus, one in the year 1631, the other in 1639, in a quarto pamphlet published at *Leipfic* 1629. (*Admonitio ad Astronomos rerumque cœlestium studiosos de miris rarisque anni 1631 phenomenonis, Veneris putæ & Mercurii in Solem incurfu.*) *Kepler* died a few days before that which he had fixed for the transit of Venus 1631; and *Gassendi* who looked for it at *Paris* was disappointed. (*Vid. Mercurius in Sole visus, & Venus invisæ.*) The truth is, a small degree of inaccuracy in the *Rudolphine Tables* gave a transit of Venus in 1631, when there was none; and gave no transit for 1639, the year in which it actually happened.

*HORROX*, a young English Astronomer, having amused himself with calculating Ephemerides from the tables of *Lansberg* (far less correct than those of *Kepler*): concluded from thence, the first of any, that Venus would pass over the Sun in the year 1639; and prepared himself to make this observation. *Lansberg's* Tables gave an error of 16' in latitude, and the *Rudolphine Tables* only an error of 8'. But the error of *Lansberg* elevated Venus too high on the Sun's disc, and that of *Kepler* made her pass entirely below it. By this means, very bad tables produced an excellent observation; they were in esteem at that time, because they had not been examined; and their author had puffed them with an imposing assurance\*. Here follows the whole of *HORROX's* observation, extracted from a paper which he drew up in 1640, a little before his death, and which *HEVELIUS* published in 1662, at the end of his *Mercurius in Sole visus*, pag. 111.

The 24th of November, old style, Venus entered the Sun's disc, about  $6\frac{1}{2}$  degrees from his nadir, that is, from a vertical line drawn through his center.

\* The *French* writers are particularly noted for their candor and politeness toward the learned of other nations. We must therefore impute the slight and very faulty account here given of Mr. *HORROX* and his observations to the author's being unacquainted with his history and studies. Mr. *HORROX's* posthumous works, published by Dr. *WALLIS*, would have informed him, that this incomparable youth was so far above the rank of an Almanack-maker, or an implicit collector from tables, that he trusted to no tables whatever, till he had corrected them from his own observations.—That he did not, as insinuated, stumble on the transit of Venus through the errors of *Lansberg*; but was led to it by his own corrections of her motions.—That from the 15th to the 23d, the last year of his life, he had cultivated all parts of Astronomy with such assiduity and success, that in a few years more, he must have carried it as far as it could go without the help of Sir *ISAAC NEWTON's* principles.



At III hours 15 minutes the distance of the centers of the Sun and Venus was  $15' 39''$ , at III hours 35 minutes it was  $14' 40''$ , and at III hours 45 minutes, the distance was  $14' 7''$ . All this on the supposition that the Sun's diameter was  $32' 36''$ ; as I find it must have been at that time. The diameter of Venus, measured several times, seemed to be at most  $1' 18''$ . If this quantity is not quite exact, the error is rather in excess; for I am sure Venus's diameter was not greater than this. And indeed, Mr. *Ckabtree*, a friend of Mr. *Horrox's*, who lived about 8 leagues off, to whom he had given notice of this phenomenon, rated it at no more than  $\frac{7}{100}$  parts of the Sun's diameter, that is, at  $1' 8''$ .

HORROX's observations were made near *Liverpool* in *Lancashire*, in latitude  $53^{\circ} 20'$ , longitude west from *Paris* 14 minutes 15 seconds of time, by projecting the Sun's disc through a telescope. And the conclusions he draws, which I have reduced as above to a solar diameter of  $32' 36''$ , are as follow. The differences in longitude  $10' 46''$ ,  $9' 42''$ ,  $9' 10''$ ; latitude of Venus  $11' 21''$ ,  $11' 0''$ ,  $10' 46''$ , for the three instants above mentioned respectively. It was necessary to insert these observations, that they may be compared with those of 1761.

In the year 1691, Mr. HALLEY gave in a paper upon the transit of Venus (*Lewthorpe's* Abridgment, pag. 434): in which he observes, from the tables then in use, that Venus returns to a conjunction in her ascending node in a period of 18 years wanting 2 days 10 hours  $52\frac{1}{2}$  minutes. But that in the second conjunction she will have got  $24' 41''$  farther to the south than in the preceding. That after a period of 235 years 2 hours 10 minutes 9 seconds, she returns to a conjunction more to the north by  $11' 33''$ ; and after 243 years wanting 43 minutes, in a point more to the south by  $13' 8''$ . But if the second conjunction is in the year next after a bissextile, it will happen a day later.

The intervals of the conjunctions at the descending node are somewhat different. The second happens in a period of 8 years wanting 2 days 6 hours 55 minutes; Venus being got more to the north by  $19' 58''$ . After 235 years 2 days 8 hours 18 minutes, she is  $9' 21''$  more southerly; if the first year is a bissextile, a day must be added. In fine, after 243 years 0 days 1 hour 23 minutes, the conjunction happens  $10' 37''$  more to the north; or a day later, if the first year was bissextile. It is supposed, as in the old style, that all the centurial years are bissextiles.

Hence

Hence Mr. HALLEY finds the years of the vulgar æra in which a transit may happen at the ascending node, in the month of November, to be these, —918, 1161, 1396, 1631, 1639, 1874, 2109, 2117 : and the transits in the month of May, old style, at the descending node, to belong to the years 1048, 1283, 1291, 1518, 1526, 1761, 1769, 1996, 2004.

In the first case, Mr. HALLEY makes the visible inclination of Venus's orbit to be  $9^{\circ} 5'$ , her horary motion  $4' 7''$ . In the latter, old style, he finds the visible inclination to be  $8^{\circ} 28'$ , and the horary motion  $4' 0''$ . In either case, the greatest possible duration of a transit is 7 hours 56 minutes.

Mr. HALLEY could even then conclude, that if the interval in time between the two interior contacts of Venus with the Sun could be measured to the exactness of a second, in two places properly situated, the Sun's parallax might be determined within its 500th part. But several years after, he explained this conclusion more fully, as follows. *Philos. Transf.* N° 348, pag. 454, or *Jones's Abridgment*, pag. 230.

[As the third article (from pag. 14 to pag. 25.) contains the Doctor's whole Dissertation here referred to, there is no occasion for repeating it again; and therefore, we shall proceed to the rest of M. De la Lande's memoir in the *Connoissance des Temps*.]

M. DE L'ISLE has used the same method of projection to find the effect of the parallaxes in the transits of Mercury (*Mem. de l'Acad.* 1743, pag. 419).

The calculations at the beginning of this book \* differ much from Mr. HALLEY's, being done from his own new tables, together with the new elements of nutation and aberration, the place of the node determined by M. De la Caille, in the year 1747, and its annual precession of  $19''.12$ , from the attraction of the other planets, as computed by myself (*Mém. de l'Acad.* 1754). This difference of elements requires several new operations in finding the effect of the parallaxes; for which purpose I shall use a method that is independent of projections, and analogous to that which I employed for computing from the observations of Mercury (*Mém. de l'Acad.* 1754).

I suppose the geocentric latitude of Venus at the time of the conjunction to be  $9' 53''.1$ ; the Sun's diameter  $31' 37''.2$ ; that of Venus  $1' 15''$ ; the Sun's parallax  $10''$ ; that of Venus  $35''.13$ ; the difference of the parallaxes  $25''.13$ ; half the time of the transit, seen from the Earth's

\* These calculations are inserted at the end of this article.



center, 3 hours 8 minutes 2 seconds. Having computed the angle of the vertical circle with the meridian, for the given time and place, I add to it  $6^{\circ} 9'$  for the angle which the meridian makes with the circle of latitude in the forenoon, and subtract the same angle in the afternoon; the sum or difference being the angle which the vertical makes with the circle of latitude. And comparing this angle with that of the orbit and circle of latitude, which is  $98^{\circ} 30'$  for the ingrefs, and  $81^{\circ} 30'$  for the egress, I get the angle of the vertical with the orbit; from whence it will be easy to deduce Venus's parallax from the Sun, both upon the orbit itself and upon a line perpendicular to it. The former, which I call the parallax of longitude, will retard both the ingrefs and egress if they happen before noon, and will accelerate them if they happen in the afternoon; each second of longitudinal parallax producing 15.0654 seconds of time, and so proportionably. The parallax of latitude will shorten or lengthen the chord which the planet describes on the Sun's disc, and consequently the semiduration of the transit; every second of this parallax will make a difference of  $12\frac{1}{100}$  seconds in the semiduration; and this difference will be of the same denomination as the former, if the vertical passes between the orbit of Venus and the circle of latitude on the Sun's disc.

In the latitude of  $56^{\circ}$  in America\*, the ingrefs and egress happening about  $65^{\circ}$  from the meridian, the angle of the vertical with the circle of declination will be  $30^{\circ} 38'$ . In the evening we find the angle of the vertical with the orbit to be  $135^{\circ} 17'$ ; the parallax of longitude  $17''.59$ , its effect in time 3 minutes 22 seconds; the effect of the parallax of latitude, of a contrary denomination,  $41' 27''$ : and thence 55 seconds for the acceleration of the ingrefs. For the egress next morning, we have  $105^{\circ} 59'$  for the angle of the vertical with the orbit;  $24''.03$  of longitudinal parallax, in time 4 minutes 50 seconds; the effect of the parallax of latitude 1 minute 44 seconds of time, of a contrary denomination. The egress therefore falls later by 3 minutes 6 seconds, and the total effect of the parallaxes increases the time of the transit by 4 minutes 1 second.

Towards the mouth of the *Ganges*, in latitude  $22^{\circ}$ , supposing the middle of the transit to be at noon, the ingrefs and egress will fall 3 hours 20 minutes distance from it: and thence the angle of the ver-

\* I imagine the place here meant is *Port-Nelson* in *North America*. But I have already shewn (pag. 26.) that observations would answer no purpose at that place, because the end of the transit will not be seen there.—Moreover, the southern parallax of Venus in latitude will contract the duration of the transit as much at *Port-Nelson* as her parallax in longitude will prolong it. So that the loss would balance the advantage, even if both the beginning and end of the transit were visible at that place.

tical with the meridian will be  $79^{\circ} 35'$ , that of the vertical and orbit in the forenoon  $25^{\circ} 6'$ ; the effect of the parallax of longitude 4 minutes 24 seconds, that of the parallax of latitude 1 minute 39 seconds, and consequently the ingress will be retarded by 6 minutes 3 seconds. In the afternoon, the angle of the vertical and orbit is  $4^{\circ} 14'$ ; the vertical falling not between the orbit and circle of latitude: so that the effect of the parallax of longitude, which is 4 minutes 50 seconds, is diminished 17 seconds by the parallax of latitude. The egress therefore is accelerated by 4 minutes 33 seconds; and the total diminution of the time of the transit is 10 minutes 36 seconds\*.

It may be difficult to send observers to 6 hours, or 90 degrees distance to the east or west of the meridian of *Paris*; but it may do tolerably well if they go to *Pondichery* or *Madras*, and better still if an Astronomer takes his station in the more northern parts of *America*; or at least in the dominions of *Russia* or *Sweden*, beyond the polar circle; that both the beginning and the end of the transit may be seen from two very distant places.

The countries which our calculus points out, as the most advantageously situated for this purpose, are, the one in 110 degrees of longitude, not far from the tropic; the other in 290 degrees of longitude, and above 60 degrees of latitude. For, although my numbers give  $58^{\circ}$  for the latitude in which the ingress and egress may be first seen, to stop there would be trusting too much to a calculation. We have indeed few places properly situated, but the northern coasts of *Hudson's Bay*, the western coasts of *Baffin's Bay*, *Repulse Bay* discovered in 1742, and some coasts almost entirely unknown.—It is pity that we cannot push on to the polar circle, by the north of *Canada*! But by good luck, whatever places in the frigid zone, and in the *Indies*, our Astronomers choose to observe in, there will still be some minutes of time for the effect of the parallax; to determine which, this is the finest opportunity that can be desired.

In our latitude of *Paris* I found the angle of the vertical with Venus's orbit  $62^{\circ} 32'$ , the parallax of altitude  $17''.44$ ; the parallax perpendicular to the orbit  $15''.47$ ; the parallax in the orbit  $8''.05$ : the effect of the first is 3 minutes 8 seconds, that of the second 2 minutes 1 second; so that there remains 1 minute 7 seconds for the retardation

\* It is plain that M. *De la Lande* here reckons the whole duration of the transit to be from the moment when Venus first touches the Sun's eastern limb to the moment of her total exit from his western; otherwise, the whole effect of the parallaxes could not be so great as he makes it; since he supposes the Sun's horizontal parallax to be only  $10''$ .



of the egress of Venus's center at *Paris*, caused by the parallax. The foremost semidiameter of Venus, as seen from the Earth's center, would take 12 minutes 8.3 seconds to move off the Sun's disc; and at *Paris* the parallax adds to this time 12.6 seconds. The hindmost semidiameter would require 11 minutes 50.7 seconds, to which the parallax adds 10.8 seconds. And therefore, from the interior contact to the egress of the center, there are 12 minutes 20.9 seconds, and from this to the total egress, 12 minutes 1.5 seconds. Every second of Venus takes 19.187 seconds of time to clear itself of the Sun's disc; but if her heliocentric latitude should be only 4" more than we have supposed it; the geocentric latitude would be increased 10"; and the time of the egress would be increased by 15.6 seconds. And the same way, one second of heliocentric latitude would produce a difference of 53.6 seconds in the duration of the transit.

In the foregoing calculations it is supposed that the logarithm of the Sun's distance from the Earth is 5.006663; that of Venus's distance from the Sun 4.861192; the Sun's diurnal motion 57' 21.3"; that of Venus, 37' 31"; Venus's diurnal geocentric motion in latitude 14' 9"; the true inclination of her orbit 3° 53' 20"; the apparent inclination referred to the Sun's center computed as at rest, 8° 30' 10", which gives the apparent inclination with respect to the fixed stars 20° 40'. The aberration of Venus in this observation will be 1".4 in latitude, and 3".7 in longitude; it will increase her apparent longitude, and diminish her latitude.

Next to the observations of the ingress and egress, the most important is that of the nearest distance of the centers of Venus and the Sun; which, at *Paris*, will happen about 6 in the morning: the *Heliameter* will be the best instrument for this purpose. When this distance is known, it will be easy to find the true geocentric latitude at the time of conjunction. The logarithm of this latitude, reduced to seconds, being added to the constant logarithm 0.82807, gives the logarithm of the node's distance; and the distance of the node taken from 2° 15' 37' 33", gives the true place of the node. This method is more exact and sure than those which authors have used.

As to the other situations of Venus, one may measure the differences of her right ascension and of her declination, her different altitudes and azimuths, or her nearest distance from the Sun's limb. If one had only a plain perspective glass, it might be employed usefully, by fixing a circle of card-paper to it, and hanging a plummet between the paper and the perspective. For, the

the Sun being thus thrown on the paper in a darkened room, will give the distance of Venus from the vertical, and from the Sun's center.

To conclude, another transit of Venus is expected on the 3d of June 1769. That and this were computed by M. *Le Gentil* (*Mém. de l'Acad.* 1753). But after this transit of 1769, 105 years must elapse before we can expect to see the like phenomenon. So far Mr. *De la Lande*.

This gentleman's calculation of the passage of Venus over the Sun in June 1761, as we have it in the *Connoissance des Temps*, is as follows.

|                                                                                                                                        | H. | M. | S. |
|----------------------------------------------------------------------------------------------------------------------------------------|----|----|----|
| June 6. The geocentric conjunction of Venus and the Sun at<br>in the morning, their common longitude being $11^{\circ} 15' 37'' 33'''$ | 6  | 25 | 30 |
| Venus's center, seen from the Earth's center, enters the Sun's disc at                                                                 | 2  | 55 | 27 |
| The nearest distance of their centers, as seen from the Earth's center<br>(9' 46''.6) at                                               | 6  | 3  | 29 |
| The beginning of the egress, as seen from the Earth's center                                                                           | 8  | 59 | 23 |
| as seen from Paris                                                                                                                     | 9  | 0  | 16 |
| Venus's center on the Sun's limb, as seen from the Earth's center                                                                      | 9  | 11 | 31 |
| as seen from Paris                                                                                                                     | 9  | 12 | 37 |
| Total egress, as seen from the Earth's center                                                                                          | 9  | 23 | 22 |
| as seen from Paris                                                                                                                     | 9  | 24 | 38 |

Deduct 9 minutes 20 seconds from the above time of the geocentric conjunction of the Sun and Venus at *Paris*, and there will remain VI hours 16 minutes 10 seconds for the time thereof at *London*; which is almost half an hour later than the time as given by Dr. HALLEY's Tables, (*See pag.* 27.) from which the above author says he made his calculations. He mentions his taking in the new elements of aberration and nutation, but as these elements can make only a very small and inconsiderable difference as to the time, and can by no means make the ending of the transit to be later as seen from *Paris* than as seen from the Earth's center, he must have fallen into a considerable mistake in some part of his calculation.

F I N I S.



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LECT.

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### DIRECTIONS for placing the COPPER-PLATES.

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